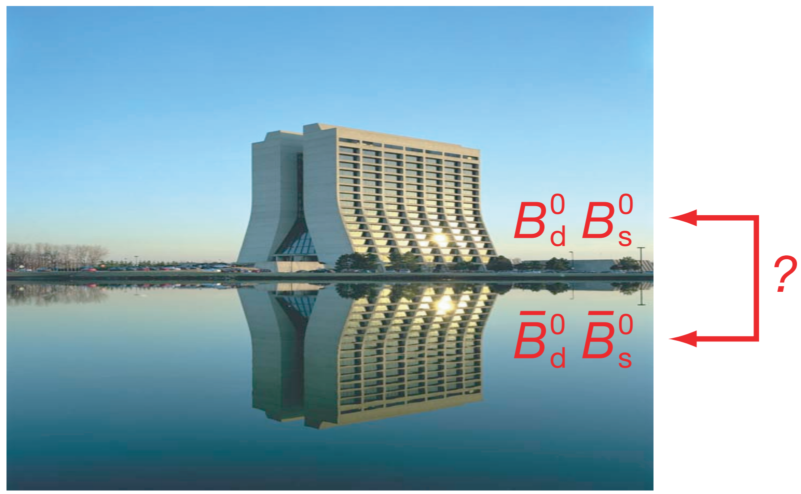
Evidence for an Anomalous Like-Sign Dimuon Charge Asymmetry



Rick Van Kooten

Indiana University

For the DØ Collaboration

Fifth Meeting on CPT AND LORENTZ SYMMETRY
Indiana University, Dept. of Physics
2 July 2010

Why the Big Fuss?

The New York Times

A New Clue to Explain Existence

TIME

Big News About Small Particles. And Why You Care

SCIENTIFIC AMERICAN

FORTE

Teadlased avastasid aine ja antiaine ebasümmeetria

Fermilab Finds New Mechanism for Matter's Dominance over Antimatter

HABERCİNİZ

SİZİN HABERCİNİZ BİZİZ

Noi descoperiri în misterul antimateriei

RL România liberă.ro

Telegraph

Haber: Evrendeki Dengelere Yeni Denklem

Atom smasher offers new clue to mystery of universe's formation

Почему мы существуем: как материя побеждает антиматерию

НОВОСТИ САМАРА сегодня

Ежедневная интернет-газета

中国新闻網 中新网

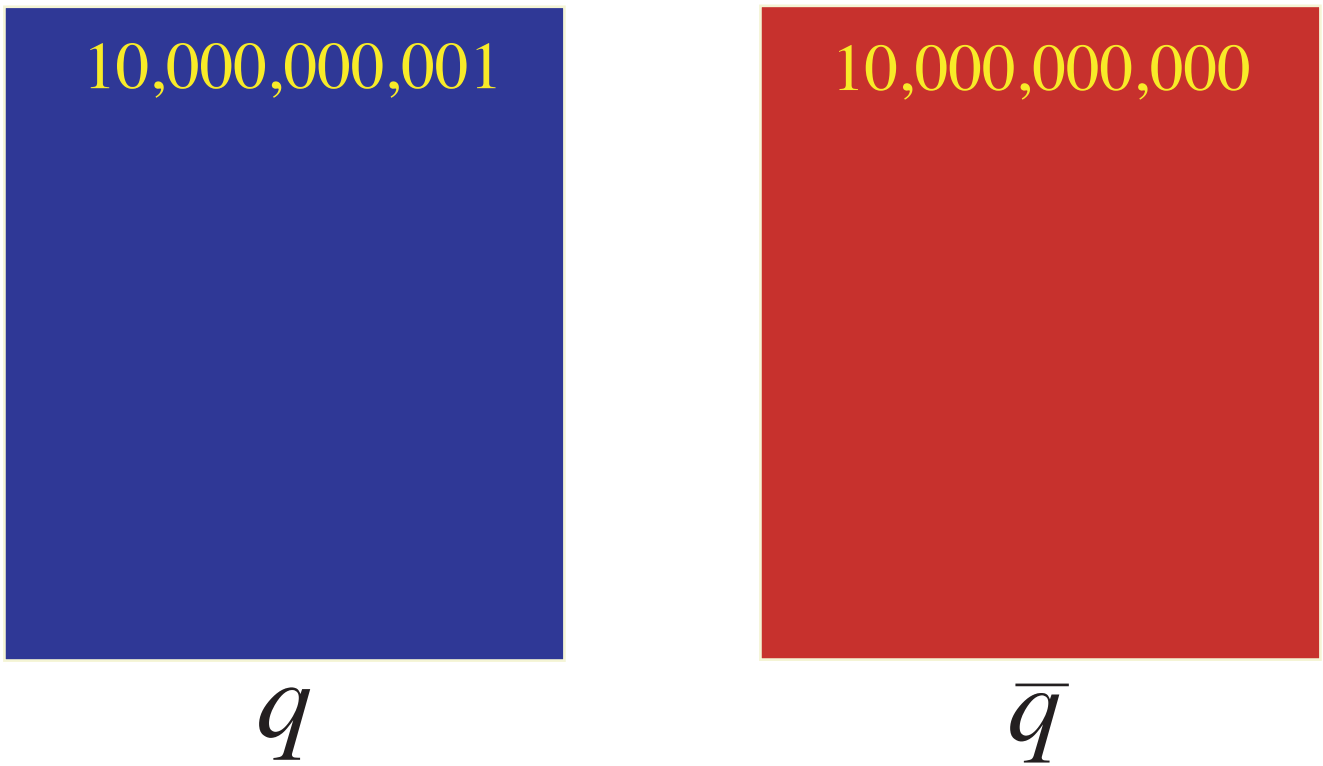
WWW.CHINANEWS.COM.CN

宇宙何以充斥物质而不是反物质？

europapress.es

El Tevatrón halla una pista para entender la composición del Universo

Baryon Asymmetry
Early Universe



due to CP violation...

Baryon Asymmetry
Current Universe

1

Us

q $\bar{q}$

The Great Annihilation

Baryon Asymmetry
Current Universe

1

•

Us

- The SM source of CP violation is insufficient to explain the imbalance between matter and antimatter
  (e.g. PRD **51**, 379 (1995))

New sources of CP violation are required to explain the matter dominance (and why we exist)

q $\bar{q}$

The Great Annihilation

Measure a Matter-Antimatter Asymmetry

As reported in arXiv:1005.2757 (16 May 2010), submitted to PRD, being followed by PRL submission:

- Measure ***raw*** asymmetry (regardless of muon source):

$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$

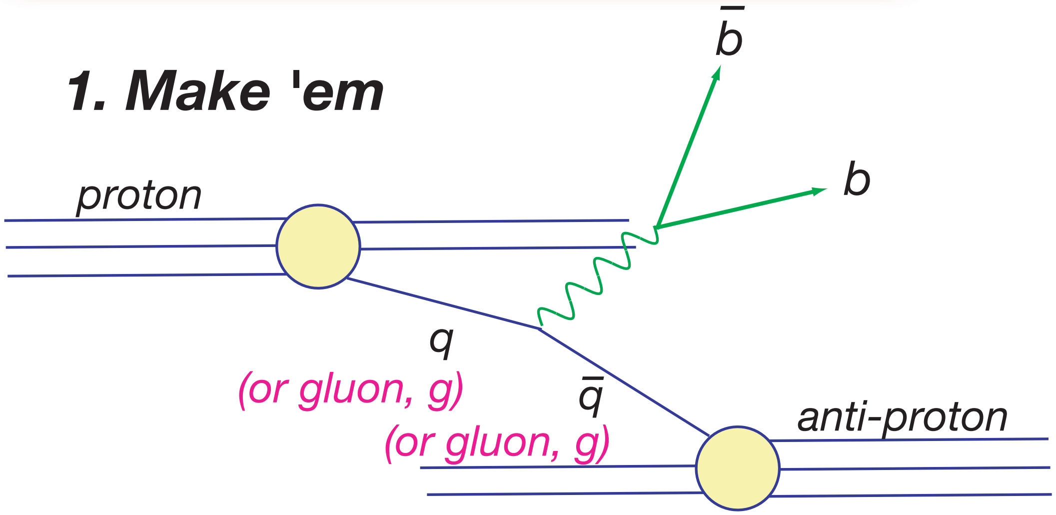
Initial $p\bar{p}$ collision state is (~)CP invariant – is the final state?

From pure physics, one of very few sources of same-sign dileptons in the same collision event is due to *B* physics

If non-zero asymmetry after correcting for backgrounds, assuming that it is coming from neutral *B* meson mixing

B Physics at the Tevatron

1. Make 'em



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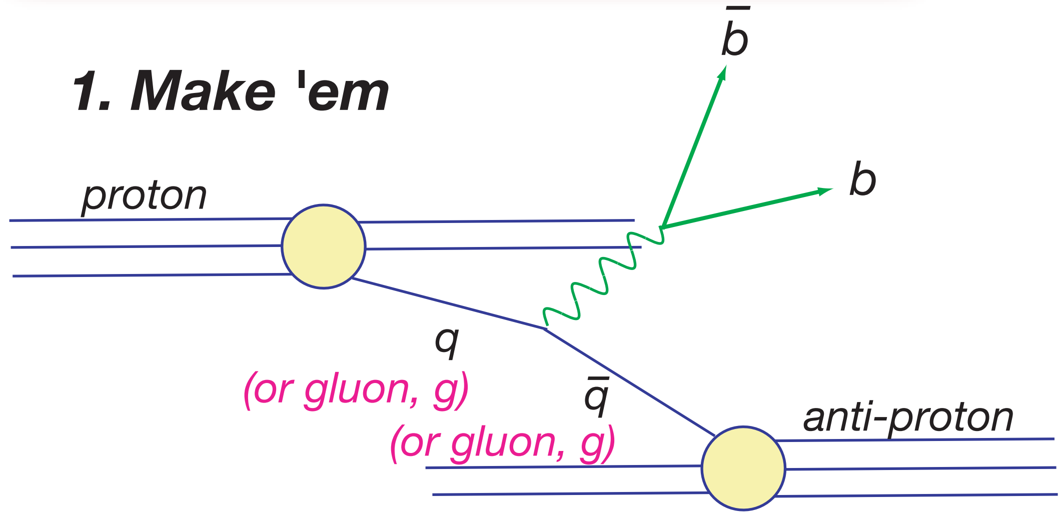
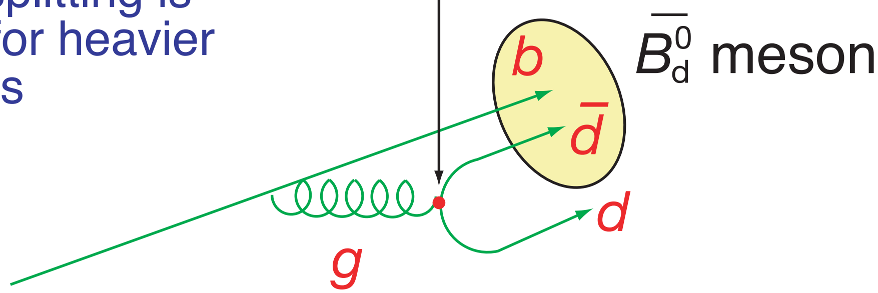


2. Hadronize

This "gluon" splitting is less probable for heavier quarks



If all states kinematically accessible:

B^+	B^0_d	B^0_s	B^+_c	Υ
$\bar{b}u$	$\bar{b}d$	$\bar{b}s$	$\bar{b}c$	$\bar{b}b$
~35%	~35%	~12%	<0.01%	

B factories

+ *b baryons...*

B Physics at the Tevatron

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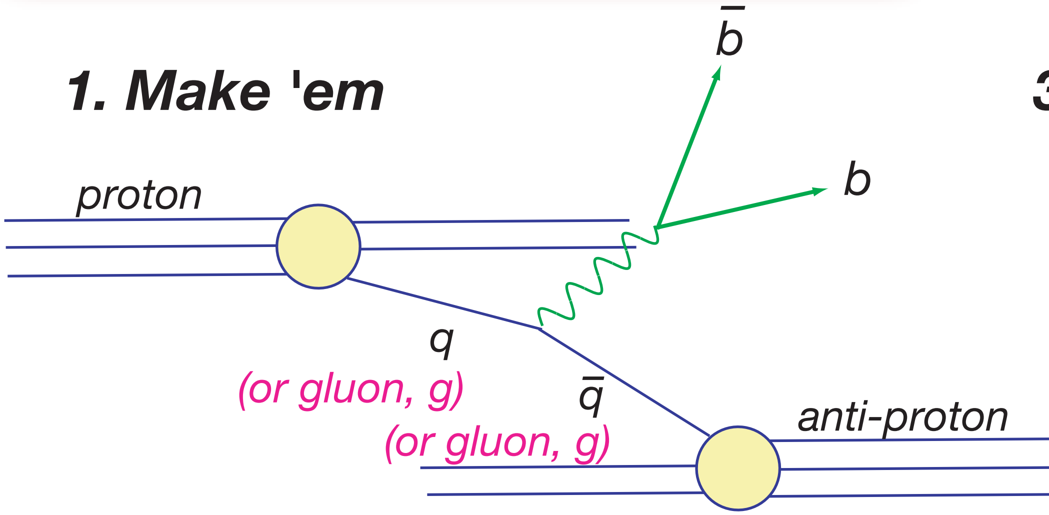

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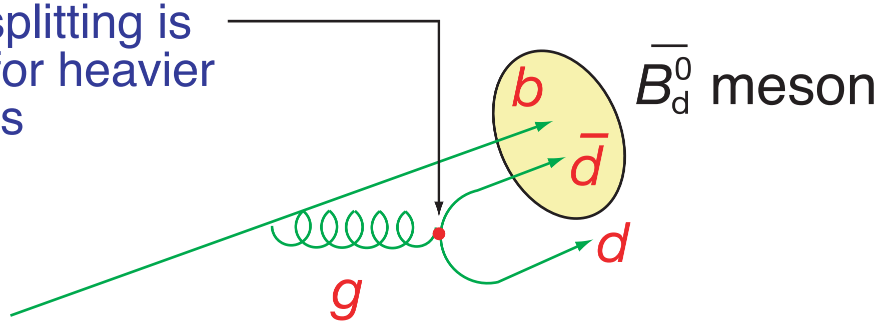
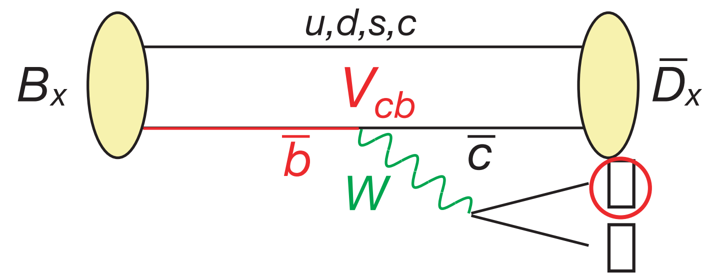


3. Decay



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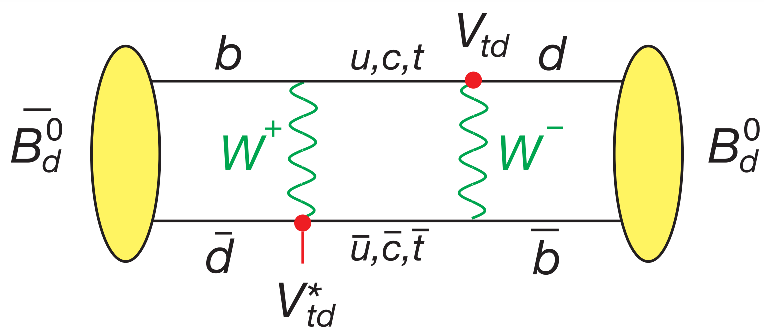
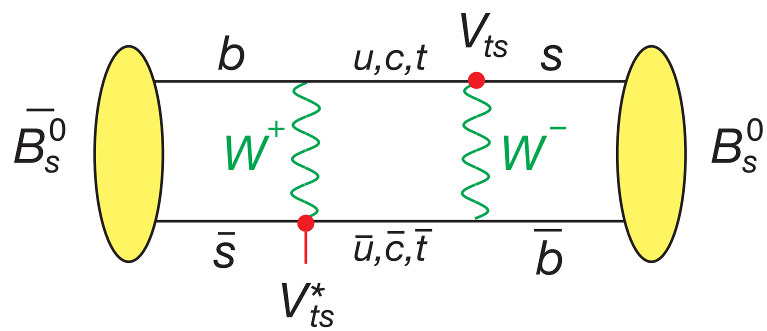
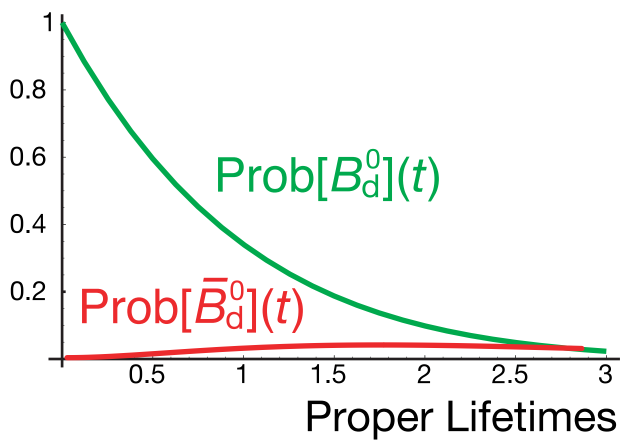
B^0-$\bar{B}^0$ Mixing and Oscillations

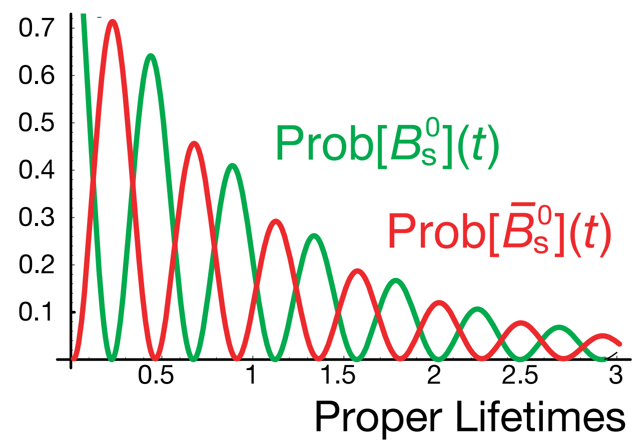




- For B_d^0



- For B_s^0



- $\Delta m_d \propto |V_{tb}^* V_{td}|^2$

  ~1 tiny

- $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$

  ~1 still small, but larger than V_{td}

Dimuon Charge Asymmetry

Direct semileptonic decay

Neutral B meson oscillation and then semileptonic decay

- Measure CP violation *in mixing* via

$$\boxed{A^b_{\rm sl} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}}$$

Number of same-sign $\mu^+\mu^+$ events

Number of same-sign $\mu^-\mu^-$ events

Dimuon charge asymmetry of semileptonic *B* decays

This is the asymmetry we are measuring

Semileptonic Charge Asymmetry

- "Right-sign" decay: $B \to \mu^+ X$
- "Wrong-sign" decay: $\overline{B} \to \mu^+ X$ *only* possible via flavor oscillation of B_d^0 and B_s^0

$$\boxed{a_{\mathrm{sl}}^b = \frac{\Gamma(\overline{B} \to \mu^+ X) - \Gamma(B \to \mu^- X)}{\Gamma(\overline{B} \to \mu^+ X) + \Gamma(B \to \mu^- X)} = A_{\mathrm{sl}}^b}$$

Semileptonic charge asymmetry

Dimuon charge asymmetry

PRL **97**, 151801 (2006)

Another way to measure!

Charge asymmetry of "wrong-sign" semileptonic *B* decays

$A^b_{\rm sl}$ at the Tevatron

- Both B^0_d and B^0_s produced at the Tevatron (unlike *B* factories at $\Upsilon(4S)$)

  with production fractions $\begin{aligned} f_d &= 0.323 \pm 0.037 \\ f_s &= 0.118 \pm 0.015 \end{aligned}$

- $A^b_{\rm sl}$ measured at the Tevatron: a linear combination of $a^d_{\rm sl}$ and $a^s_{\rm sl}$

$$\boxed{A^b_{\rm sl} = (0.506 \pm 0.043)\, a^d_{\rm sl} + (0.494 \pm 0.043)\, a^s_{\rm sl}}$$

Tevatron has access to ***both***

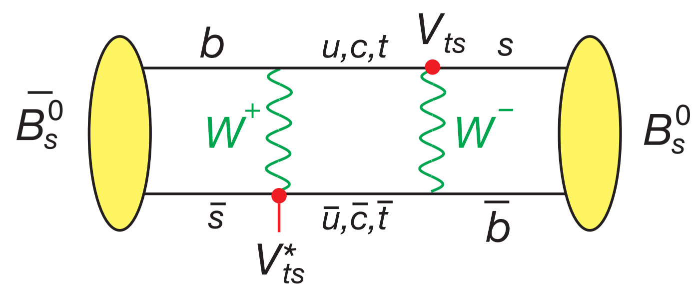
B Factories can provide independent measurement of $a^d_{\rm sl}$

Neutral Meson Mixing

Particularly for B_s^0

Weak Eigenstates propagate according to Schrodinger:

$$i\frac{d}{dt}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix} \begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$



Diagonalize: like a coupled oscillator; modes are the propagating states

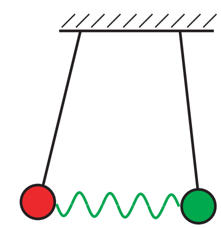
Mass Eigenstates: $|B_s^H\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$ *Heavy* $\quad |B_s^L\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$ *Light*

If CP conserved in mixing, $p=q$ $\quad |B_s^H\rangle = |B_s^{odd}\rangle \quad |B_s^L\rangle = |B_s^{even}\rangle$

$$\Delta m_s = M_H - M_L \sim 2|M_{12}|$$

$$\Delta\Gamma_s^{CP} = \Gamma_{even} - \Gamma_{odd} \sim 2|\Gamma_{12}|$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|\cos\phi_s$$



$$\Gamma_s = \frac{\Gamma_L + \Gamma_H}{2} \; ; \quad \tau = \frac{1}{\Gamma_s}$$

$$\phi_s^{SM} = \arg\left[-\frac{M_{12}}{\Gamma_{12}}\right] \sim 0.004 \text{ in SM}$$

CP-violating!

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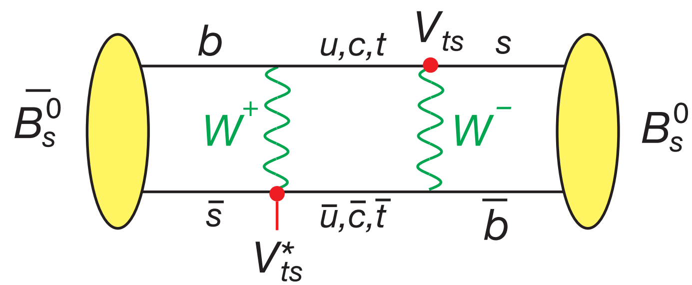

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(r) (s) If CPT violated

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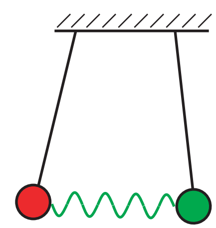

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Diagonalize

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$$\Delta m_s = M_H - M_L \sim 2|M_{12}|$$ Sensitive to new physics

$$\Delta\Gamma_s^{CP} = \Gamma_{even} - \Gamma_{odd} \sim 2|\Gamma_{12}|$$ Not sensitive to new physics

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|\cos\phi_s$$ *Very* sensitive to new physics

$$\Gamma_s = \frac{\Gamma_L + \Gamma_H}{2} \; ; \quad \tau = \frac{1}{\Gamma_s}$$

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A^b_{sl} and CP Violation

- Can now connect:

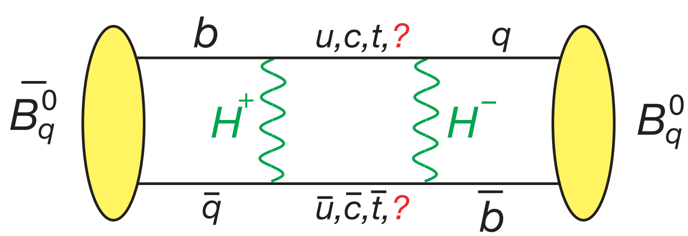
$$a^q_{sl} = \frac{\Delta\Gamma_q}{\Delta M_q} \tan\phi_q \qquad = \frac{1-|q/p|^4}{1+|q/p|^4}$$

- Leading to the SM prediction of a very small asymmetry:

$$\boxed{A^b_{sl}(SM) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}}$$

(Lenz, Nierste, hep-ph/0612167)

- New physics contribution can significantly change this value by changing the CP-violating phases ϕ_d and ϕ_s



e.g., 4th gen., Higgs, SUSY, leptoquarks,etc.

- SM value too small to measure with our current experimental precision → simplifies detection of possible deviation

Experimental Strategy

- Measure ***raw*** asymmetries (regardless of muon source):

$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} \qquad a = \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)}$$

Upper-case symbols for dimuons *Lower-case symbols for single muons*

Both contain contributions from A_{sl}^b , other processes producing muons, plus detector-related backgrounds

Blinded Analysis

Central value of A_{sl}^b extracted from full data set only after the analysis method and all statistical and systematic uncertainties finalized

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Lower-case symbols for single muons

Both contain contributions from $A^b_{\rm sl}$, other processes producing muons, plus detector-related backgrounds

$$A = KA^b_{\rm sl} + \underline{A_{\rm bkg}}$$

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- Using minimal input from simulation, determine detector-related backgrounds/asymmetries

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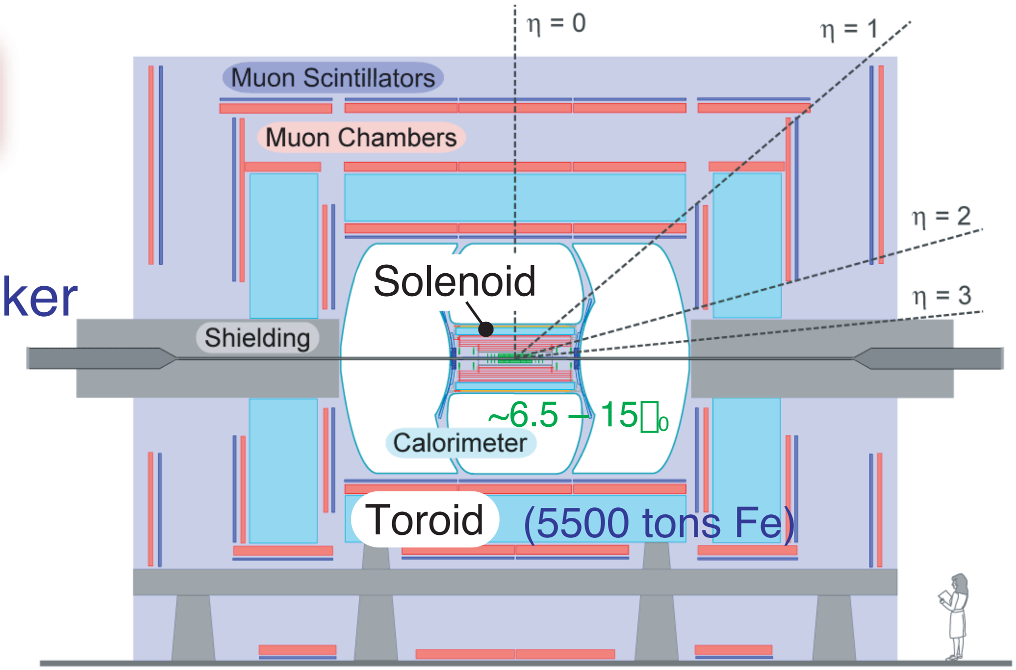
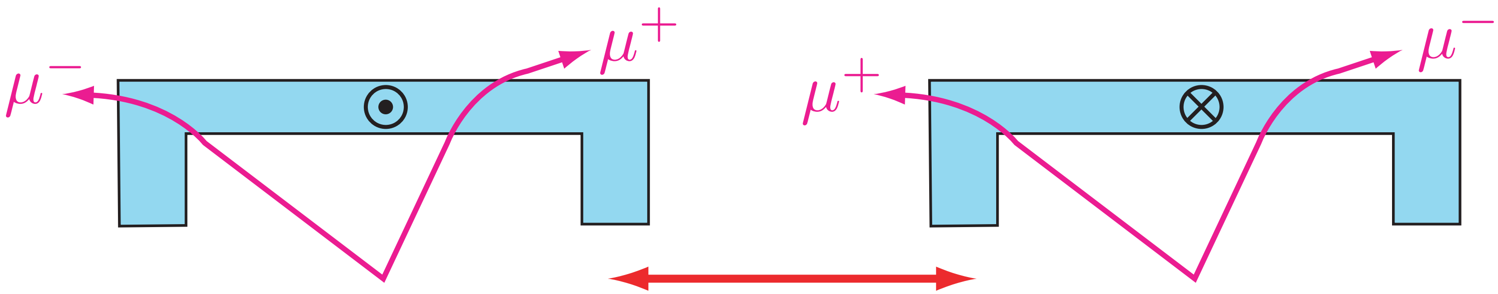
- Determine fraction of single muons and like-sign dimuons from mixed *B* hadron decays $(K > k)$

- Exploit different signal and (correlated!) background content of both asymmetries to minimize uncertainty on $A^b_{\rm sl}$

Strengths of DØ Detector



- Excellent muon coverage out to $|\eta| < 2$, non-gaseous tracker
- Reverse polarities of solenoid and toroid reversed every ~ 2 weeks
- Four roughly equal-sized samples $(++, --, +-, -+)$



Swap polarities

- Difference in reconstruction efficiency between positive and negative particles minimized

→ helps cancel/reduce many detector charge asymmetries!
(cancel to first order ~3% → ~0.1%)

Raw Asymmetries

Count (billions!!)

$$\boxed{a = \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)} = (0.955 \pm 0.003)\%}$$

From 1.5×10^9 muons in inclusive sample

$$\boxed{A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = (0.564 \pm 0.053)\%}$$

From 3.7×10^6 events in like-sign dimuon sample

Both raw asymmetries have significant backgrounds, distinguish:

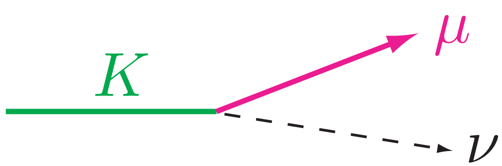
$$A = KA^b_{\rm sl} + A_{\rm bkg} \qquad\qquad a = kA^b_{\rm sl} + a_{\rm bkg}$$

See later that $(a \simeq a_{\rm bkg})$

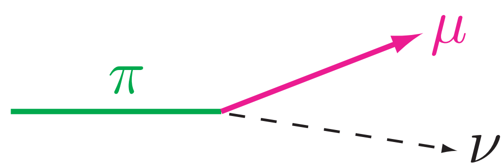
- Asymmetries in detector backgrounds and reconstruction efficiencies
- "Dilution" due to other "prompt/physics" sources of muons

Detector-Related Backgrounds

- Decays in flight, e.g.: $K \rightarrow \mu\nu$ and $\pi \rightarrow \mu\nu$



$c\tau = 3.7\,\mathrm{m}$



$c\tau = 7.8\,\mathrm{m}$

In tracker, calorimeter, magnet, ...

- Punch-through (shower in material), sail-through of π, K, p

...that all both lead to their identification as a muon

- Muon misidentification (muon segment associated to wrong charged track)

(• Other sources of muons, "prompt/physics" accounted for in dilution factors)

$b \rightarrow \mu, c \rightarrow \mu, b \rightarrow c \rightarrow \mu, J/\psi \rightarrow \mu^+\mu^-, \rho \rightarrow \mu^+\mu^-$

Detector-Related Backgrounds

Inclusive muon

Like-sign dimuon
(only linear terms kept)

$$a_{\text{bkg}} = f_K a_K + f_\pi a_\pi + f_p a_p + (1 - f_{\text{bkg}})\delta$$
$$A_{\text{bkg}} = F_K A_K + F_\pi A_\pi + F_p A_p + (2 - F_{\text{bkg}})\Delta$$

- f_K, f_π, f_p ; F_K, F_π, F_p fractions of each particle identified as muons
- a_K, a_π, a_p ; A_K, A_π, A_p charge asymmetry of each particle track identified as a muon
- δ ; Δ charge asymmetry of muon reconstruction
- $f_{\text{bkg}} = f_K + f_\pi + f_p$; $F_{\text{bkg}} = F_K + F_\pi + F_p$

The Big One: Kaons

Inclusive muon

Like-sign dimuon
(only linear terms kept)

$$a_{\rm bkg} = f_K a_K + f_\pi a_\pi + f_p a_p + (1 - f_{\rm bkg})\delta$$
$$A_{\rm bkg} = F_K A_K + F_\pi A_\pi + F_p A_p + (2 - F_{\rm bkg})\Delta$$

Dominant contribution (other asymmetries ~10 times smaller)

- Detector made of matter
- Different interaction cross-section for K^+ and K^-

...since $K^- N \to Y\pi$ has no $K^+ N$ equivalent

e.g., at $p_K = 1\,\mathrm{GeV}$

$$\sigma(K^- d) \simeq 80\,\mathrm{mb} \qquad \sigma(K^+ d) \simeq 33\,\mathrm{mb}$$

- K^+ travel further than K^- in material, more chance to decay to μ^+
- K^+ has more chance to punch-through/sail-through than K^-

$\boxed{\text{Positive asymmetry in nature} \rightarrow \text{Measure in data!}}$

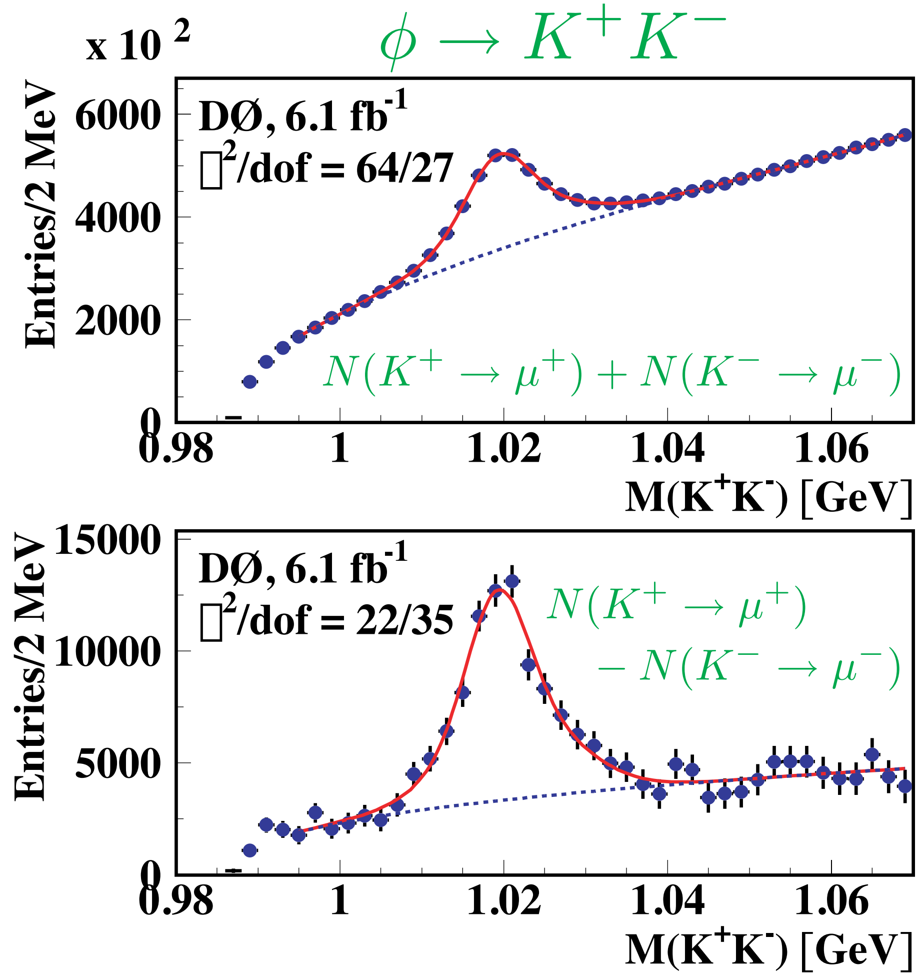
The Big One: Kaons

- Reconstruct $\phi \to K^+K^-$ where one of the K mesons is reconstructed as a muon
  $K^{*0} \to K^+\pi^-$

- Compare K^+ and K^-,
  → subtract

- Correction factor for decays-in-flight in tracker causing track parameter change due to kink
  (not reconstructed in resonance)

- ϕ results agree well with K^{*0}
  → combine



Muon Reconstruction Asymmetry

Saved by polarity flips

$$a_{\rm bkg} = f_K a_K + f_\pi a_\pi + f_p a_p + (1 - f_{\rm bkg})\delta$$
$$A_{\rm bkg} = F_K A_K + F_\pi A_\pi + F_p A_p + (2 - F_{\rm bkg})\Delta$$

- J/ψ decays

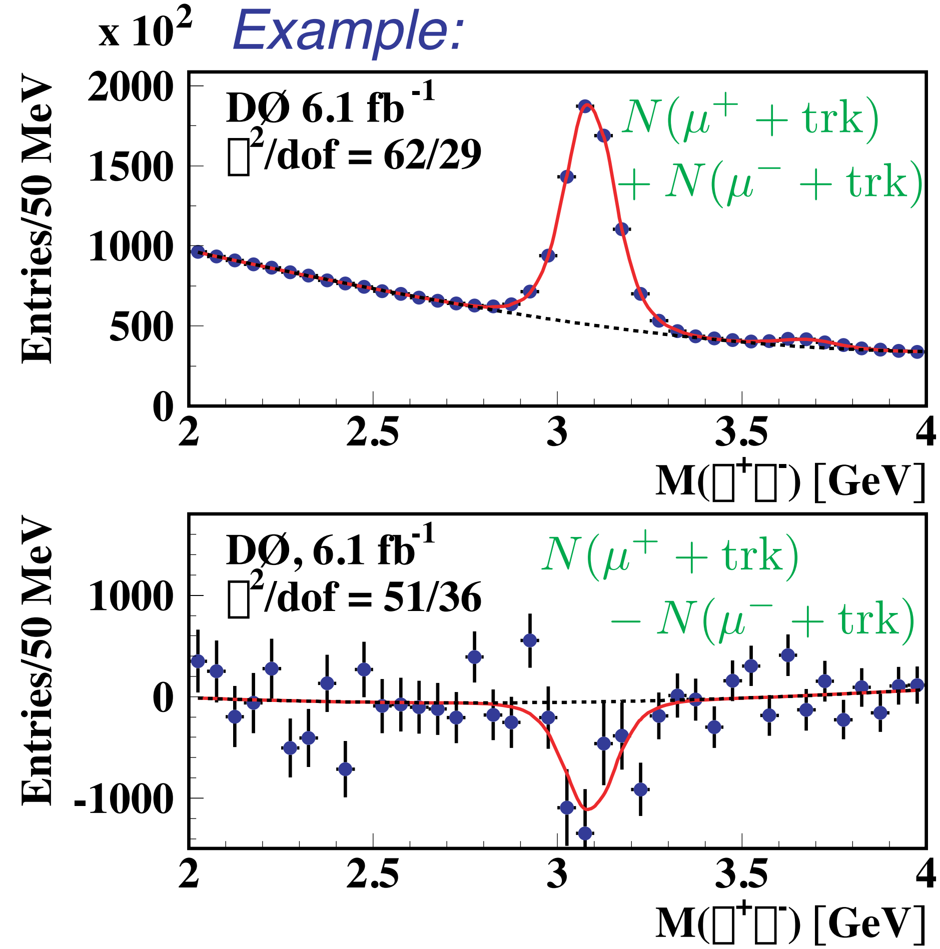
- Measure asymmetry in □ + track and dimuon decays

$$\delta = (-0.076 \pm 0.028)\%$$
$$\Delta = (-0.068 \pm 0.023)\%$$

Small residual asymmetries direct consequence of regular reversal of magnet polarities!

(otherwise $\mathcal{O}(3\%)$)

Example:



Dilution Factors

The physics...

$$a - a_{\rm bkg} = kA^b_{\rm sl}$$
$$A - A_{\rm bkg} = KA^b_{\rm sl}$$

- Multiple physics processes contribute to the inclusive and like-sign dimuon samples

- Use simulation to determine dilution factors k and K

  (decay processes are well measured)

$$k = 0.041 \pm 0.003$$
$$K = 0.342 \pm 0.023$$

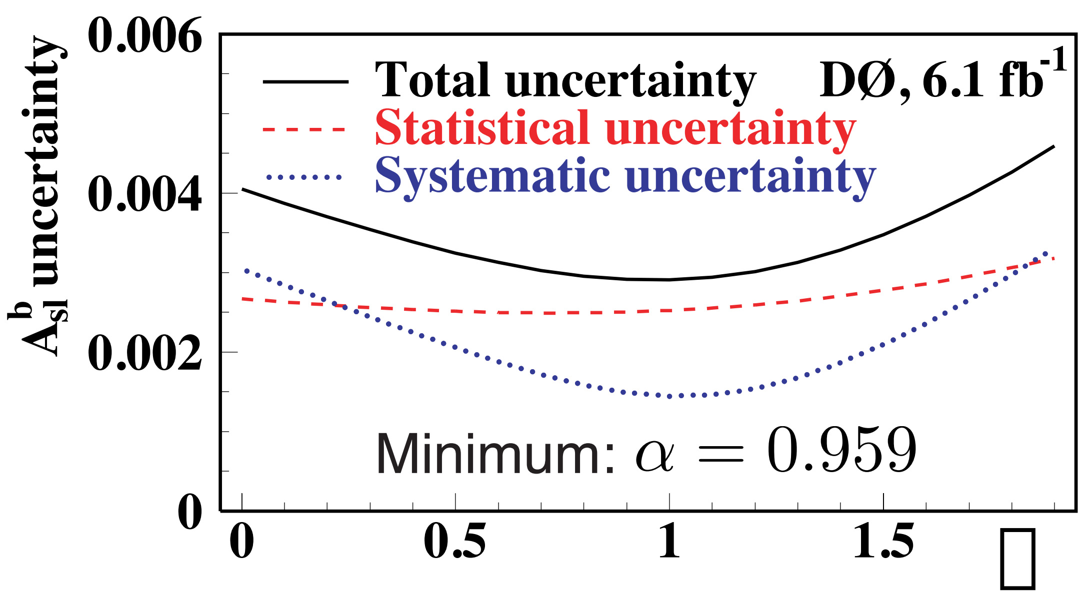
	Process		
T_1	$b \rightarrow \mu^- X$		
T_{1a}	$b \rightarrow \mu^- X$ (non-oscillating)		
T_{1b}	$\bar{b} \rightarrow b \rightarrow \mu^- X$ (oscillating)	$\longrightarrow A$	$A^b_{\rm sl}$
T_2	$b \rightarrow c \rightarrow \mu^+ X$	$\longrightarrow A$	
T_{2a}	$b \rightarrow c \rightarrow \mu^+ X$ (non-oscillating)		
T_{2b}	$\bar{b} \rightarrow b \rightarrow c \rightarrow \mu^+ X$ (oscillating)		$A^b_{\rm sl}$
T_3	$b \rightarrow c\bar{c}q$ with $c \rightarrow \mu^+ X$ or $\bar{c} \rightarrow \mu^- X$		
T_4	$\eta, \omega, \rho^0, \phi(1020), J/\psi, \psi' \rightarrow \mu^+\mu^-$		
T_5	$b\bar{b}c\bar{c}$ with $c \rightarrow \mu^+ X$ or $\bar{c} \rightarrow \mu^- X$	$\longrightarrow A$	
T_6	$c\bar{c}$ with $c \rightarrow \mu^+ X$ or $\bar{c} \rightarrow \mu^- X$		

Reducing Total Uncertainty

- Like-sign dimuons and single muons have common sources of backgrounds. Partially cancel in the linear combination:

$$\boxed{A' = (A - \alpha a) = (K - \alpha k)A^b_{sl} + (A_{\text{bkg}} - \alpha a_{\text{bkg}})}$$

Choose α to minimize total uncertainty on A^b_{sl}



Expected to be close to 1 since
the backgrounds are highly correlated

Result

Putting it all together

- α technique, to constrain background (reduced systematic)

$$\boxed{A^b_{\rm sl} = (-0.957 \pm 0.251\,({\rm stat}) \pm 0.146\,({\rm syst}))\%}$$

3.2 deviation from

$$\boxed{A^b_{\rm sl}(SM) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}}$$

- Consistent with prior DØ dimuon result with 1.0 fb^{-1} (Phys. Rev. **D** 74, 092001 (2006))

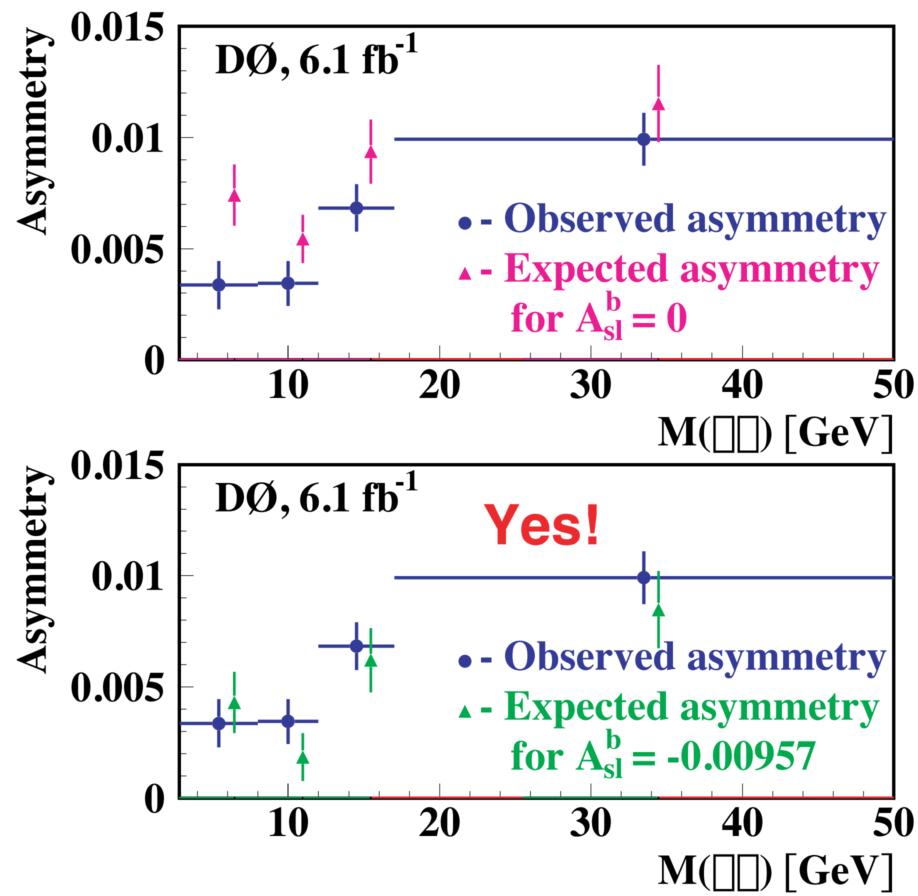
$$A^b_{\rm sl} = (-0.53 \pm 0.31)\%$$

1.7 deviation from SM

Consistency Checks

- No lifetime or flavor tagging that guarantees from *B* hadrons

→ Does it behave as expected kinematically?



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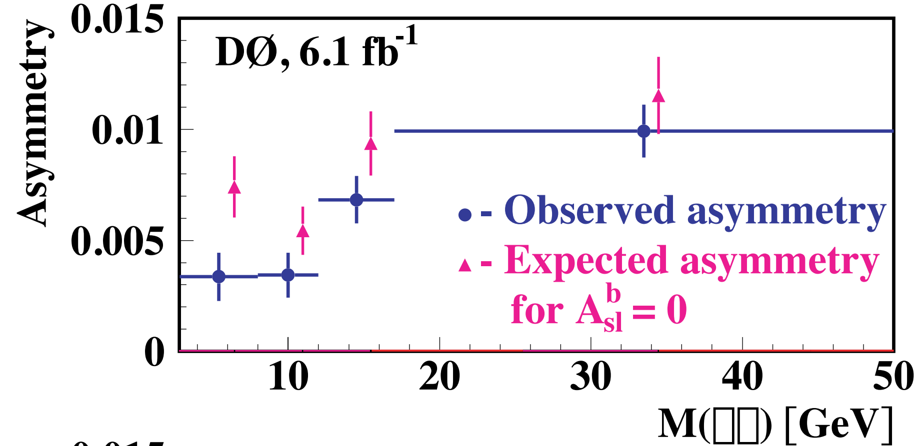
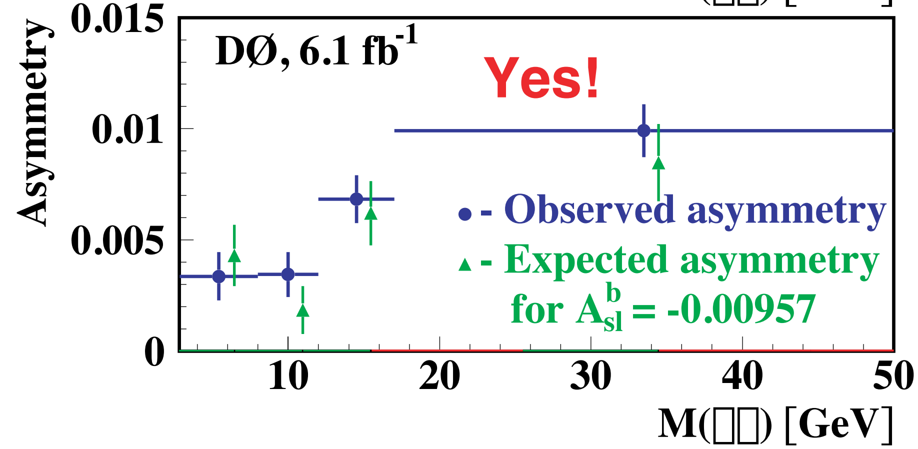
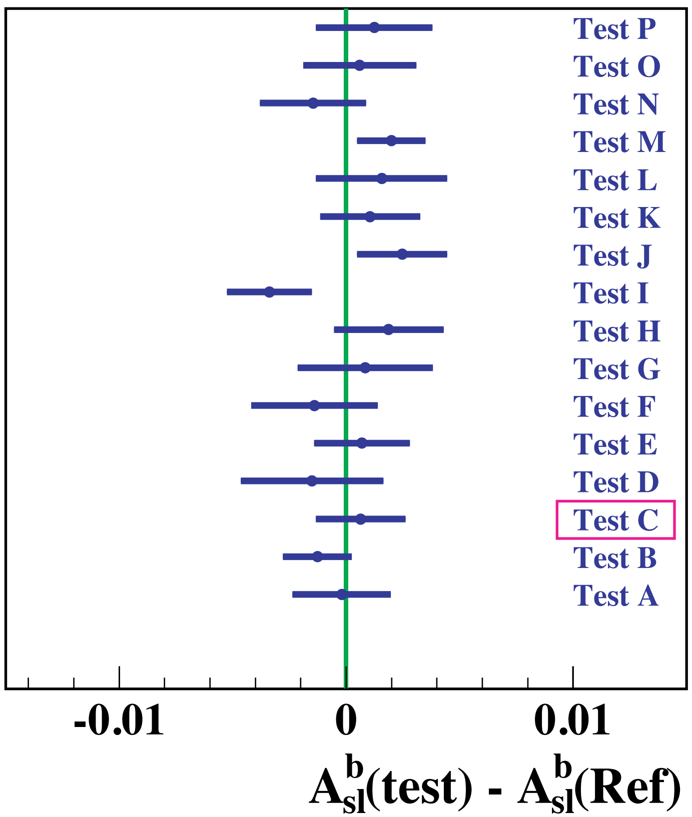




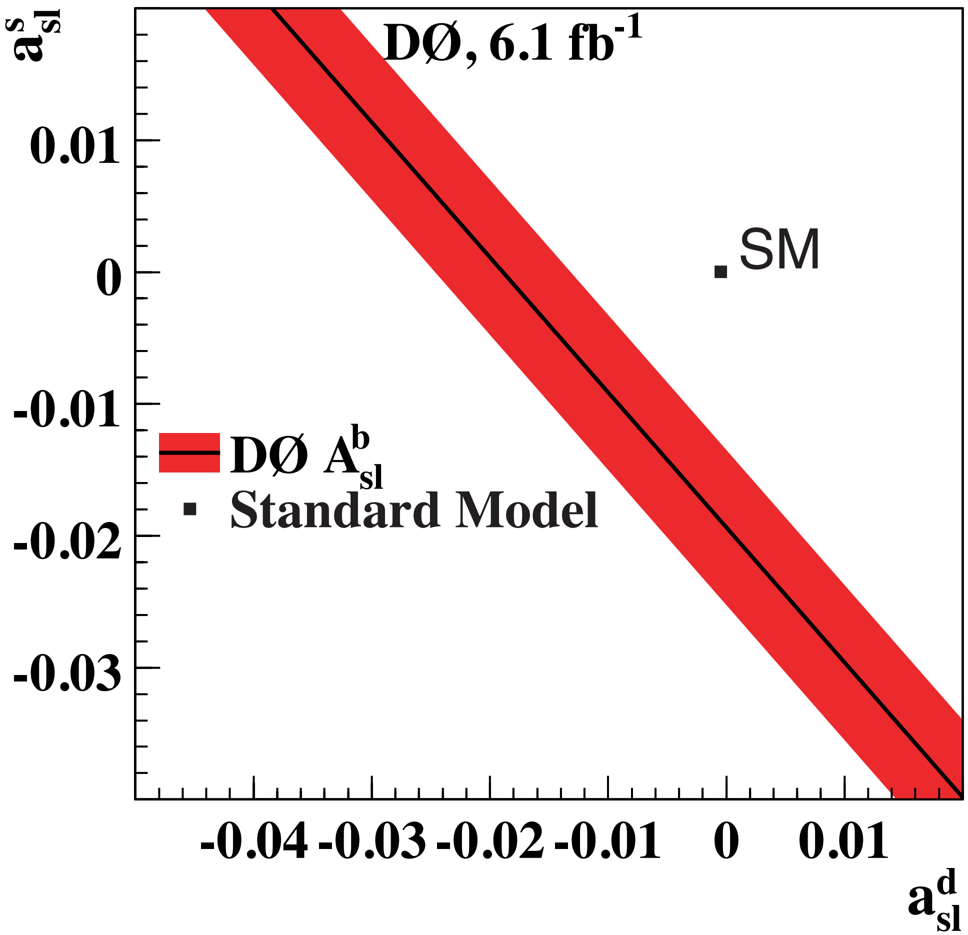


- Modify selection, split sample tests, changes raw A by up to 150% due to variations in background
- Measured value of A^b_{sl} remains stable

Consistency with Other Results

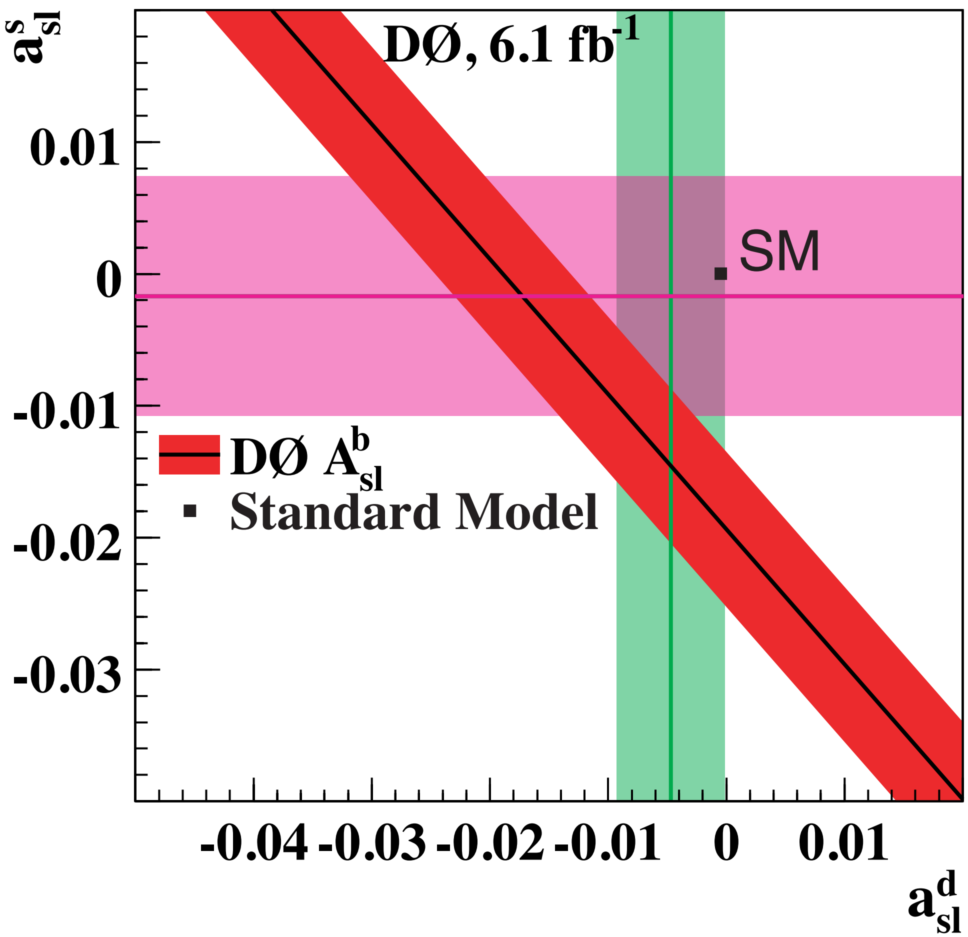
- Recall that measured asymmetry is a linear combination:

$$A^b_{\mathrm{sl}} = 0.506\, a^d_{\mathrm{sl}} + 0.494\, a^s_{\mathrm{sl}}$$



Consistency with Other Results

- Consistent with world average of $a_{\rm sl}^{d} = (-0.47 \pm 0.46)\%$ from *B* factories (BaBar, Belle, CLEO; HFAG)



- Consistent with DØ direct measurement of $a_{\rm sl}^{s} = (-0.17 \pm 0.91)\%$ using $B_s^0 \to D_s \mu \nu$ (arXiv:0904.3907, sub. to PRD)

CP Violation

Three kinds:

- In decay: $|\mathcal{A}_f|^2 \neq |\bar{\mathcal{A}}_{\bar{f}}|^2$

$$\overline{B}^0 \to K^-\pi^+$$
$$B^0 \to K^+\pi^-$$

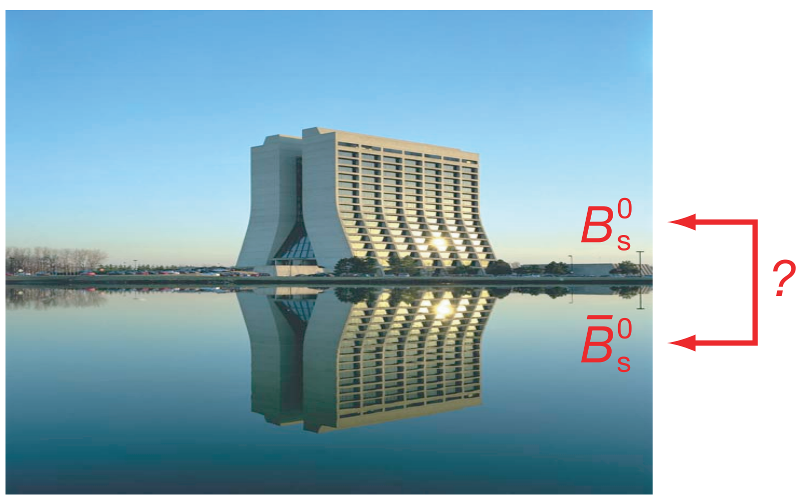
Different!

- In mixing: $\boxed{|q/p|^2 \neq 1}$

Dimuon Charge Asymmetry

- In interference of decay and mixing amplitudes

$$\phi_s \neq 0 \text{ or } \pi$$



Extracting $a^s_{\rm sl}$

- Input world average of $a^d_{\rm sl} = (-0.47 \pm 0.46)\%$ from *B* factories into:

$$A^b_{\rm sl} = (0.506 \pm 0.043) a^d_{\rm sl} + (0.494 \pm 0.043) a^s_{\rm sl}$$

$$\boxed{a^s_{\rm sl} = (-1.46 \pm 0.75)\%}$$

compare to prediction

$$\boxed{a^s_{\rm sl}(SM) = (-0.0021 \pm 0.0006)\%}$$

- Deviation not as large due to additional uncertainties, but allows for interesting comparison/combination:

$$a^s_{\rm sl} = \frac{|\Gamma^{12}_s|}{|M^{12}_s|} \sin\phi_s = \frac{\Delta\Gamma_s}{\Delta M_s} \tan\phi_s$$

$$\phi_s = \underset{(0.0042 \pm 0.0014)}{\phi^{SM}_s} + \phi^{NP}_s$$

CP Violation: Another way to test

Golden mode,
Tevatron

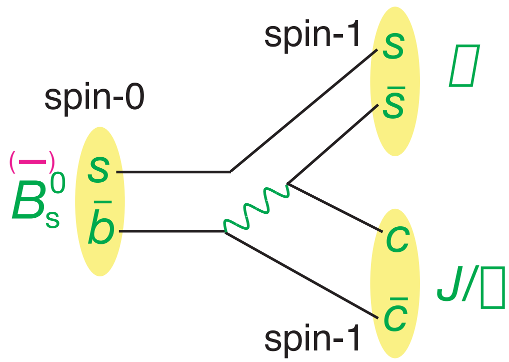
$$\begin{tikzcd} B_s^0 \arrow[rr, "\sin 2\beta_s"'] \arrow[dr, "\text{mix}"'] & & J/\psi\phi \\ & \bar{B}_s^0 \arrow[ur, "\text{mix}"'] & \end{tikzcd}$$

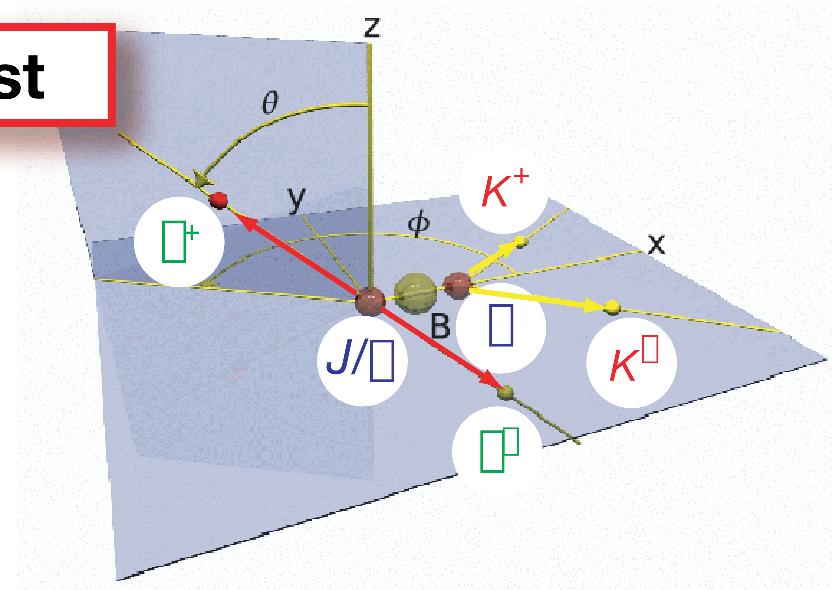
CP violation through
interference of diagrams
with and w/o mixing

$$\phi_s^{J/\psi\phi} = -2\beta_s = \underbrace{-2\beta_s^{SM}}_{-(0.038\,\pm\,0.002)} + \phi_s^{NP}$$

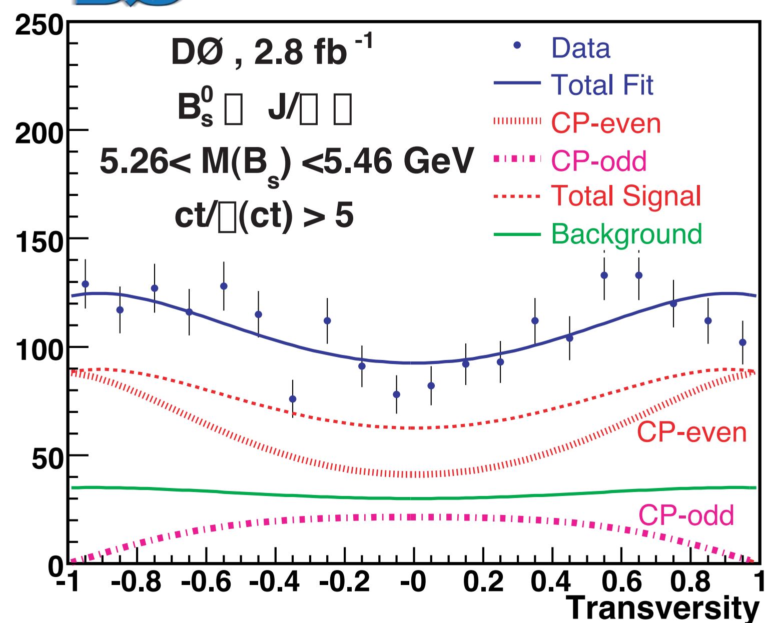
If new physics in mixing, same new phase angle in $B_s^0 \rightarrow J/\psi\phi$!

CP Violation: Another way to test





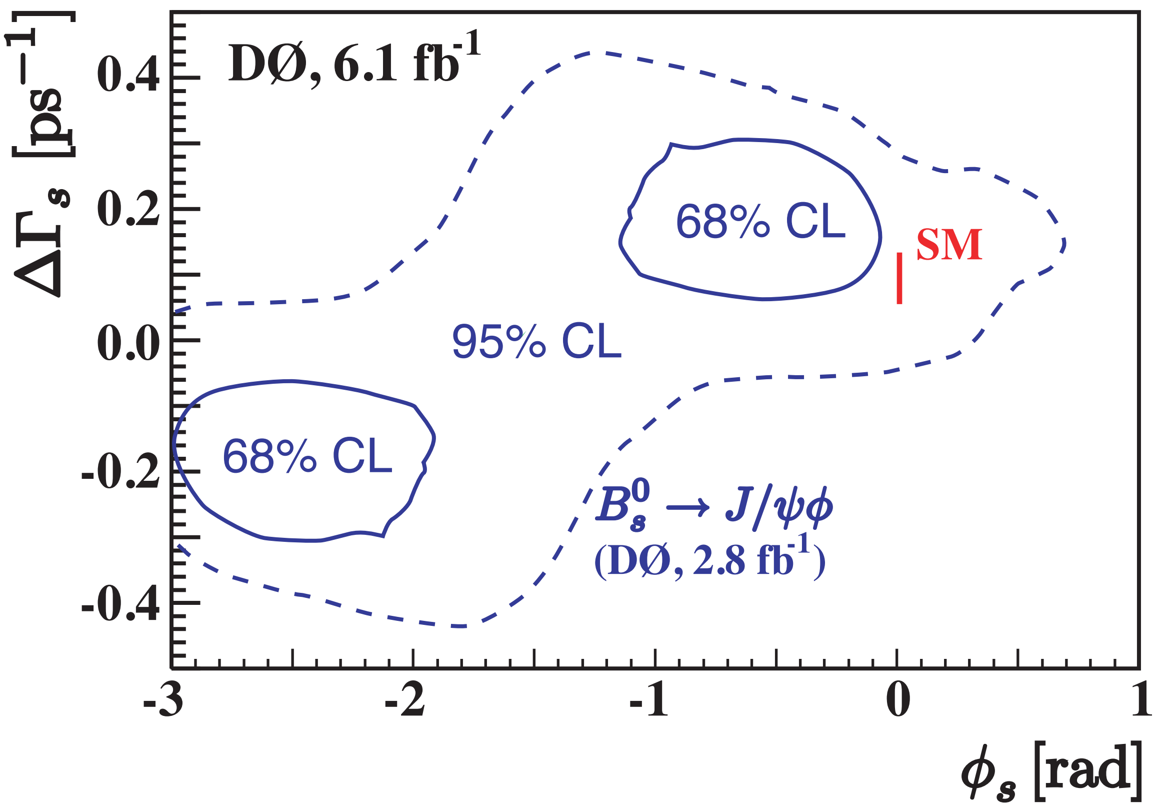
DØ analysis led by Daria Zieminska here at IU



- Decays into two vector mesons that are either *CP*-odd (*L*=1) or *CP*-even (*L*=0,2)
- Time-dependent angular distributions allow separation of components
- Simultaneous fit to lifetime and three angles "transversity basis"

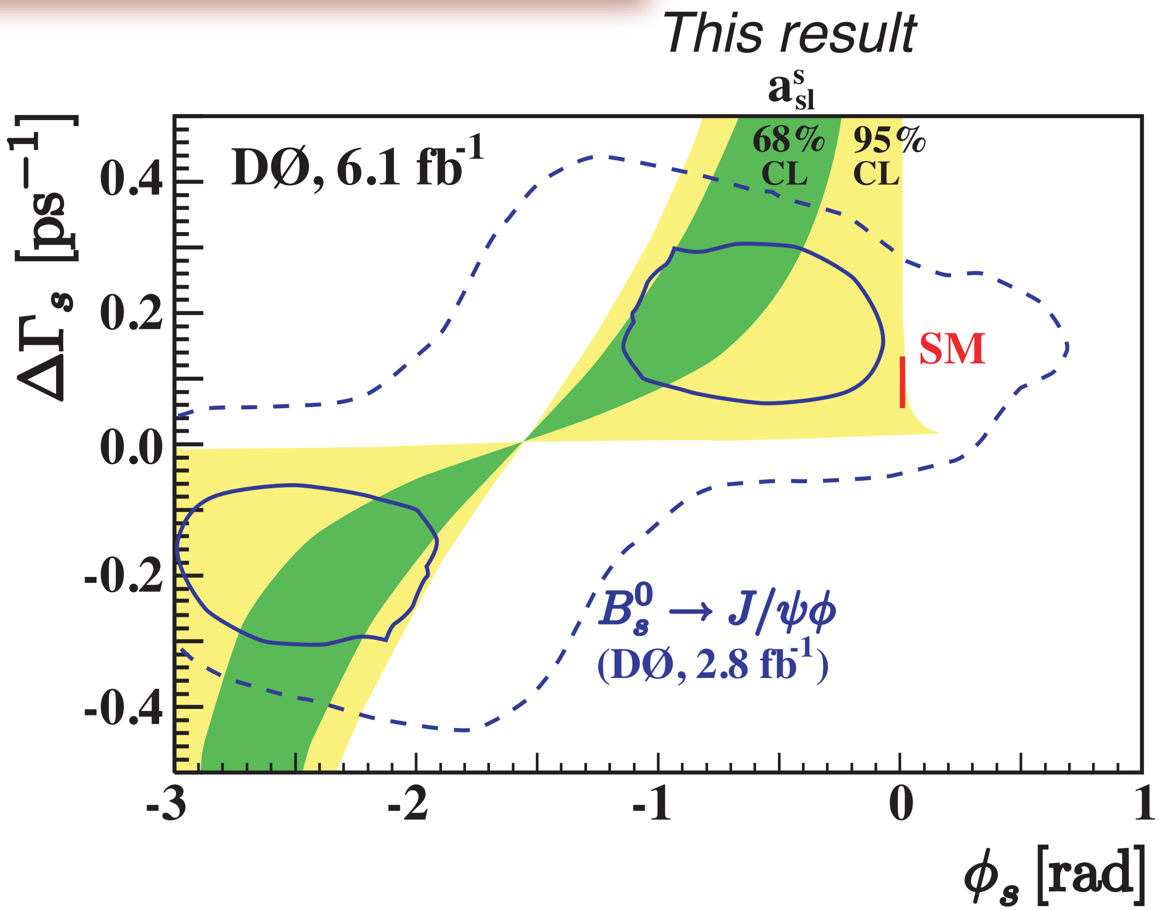
Comparisons using a_{sl}^{s}

PRL 101, 241801 (2008)
+ DØ Note 5933-CONF (2009)
(systematics & coverage adjusted)



Comparisons using a_{sl}^{s}

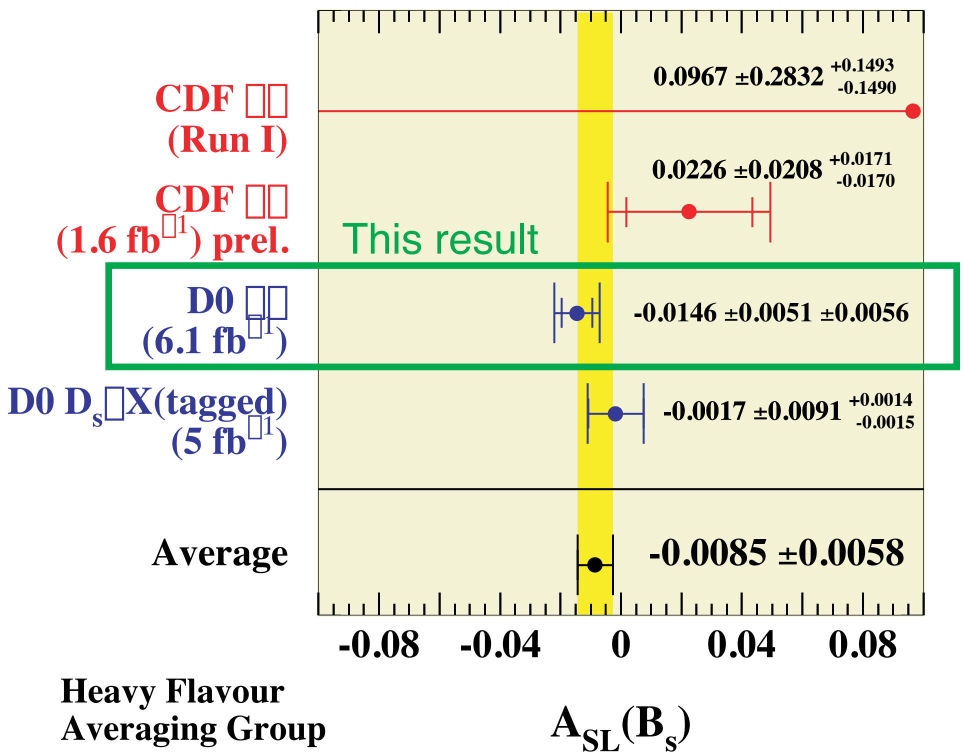
DØ Only

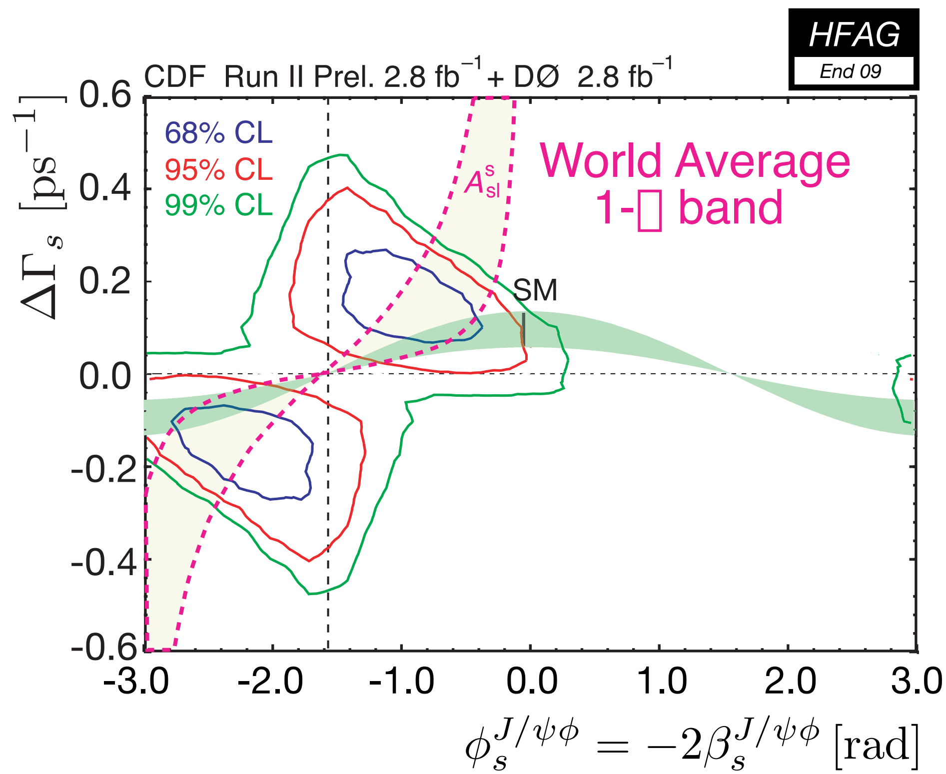


$$a_{\rm sl}^{s} = \frac{\Delta\Gamma_s}{\Delta M_s}\tan\phi_s$$

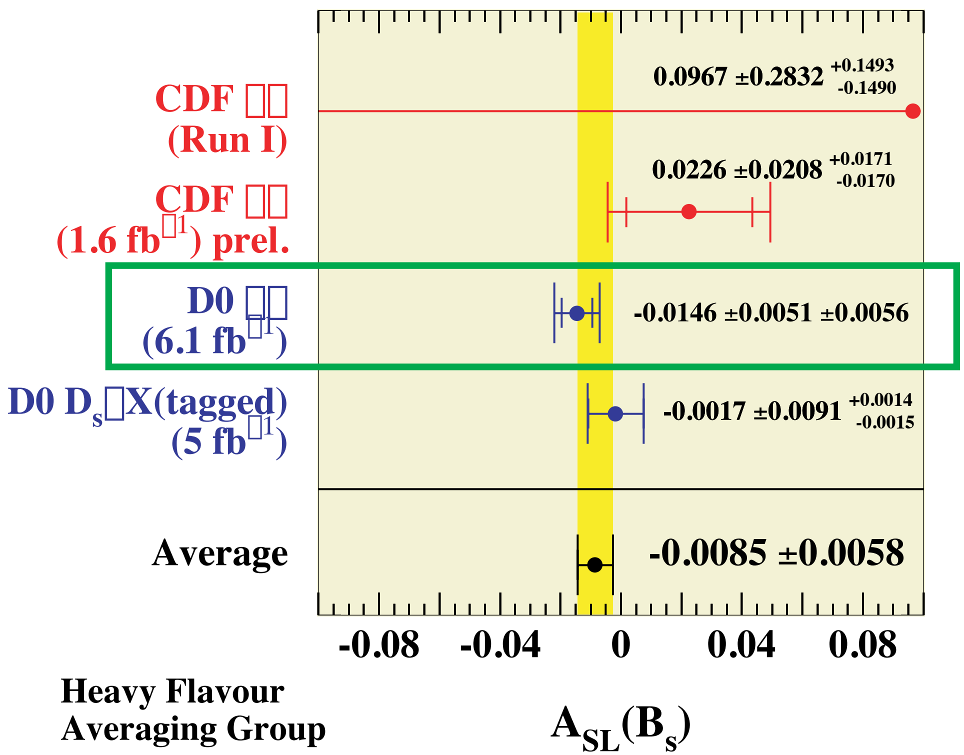
leads to constraints on $\Delta\Gamma_s$ and ϕ_s

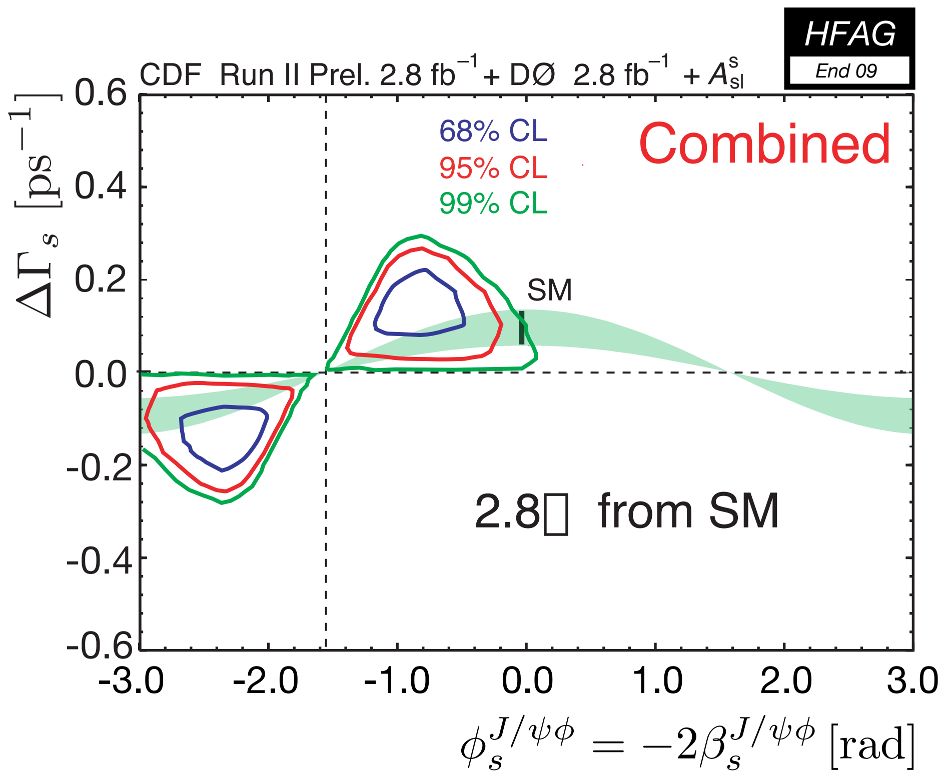
Comparisons using a^s_{sl}





Comparisons using a_{sl}^{s}





Implications for *CPT*?

(work of talk author; not vetted by DØ Collaboration...)

- From formalism of Kostelecky, Phys. Rev. **D64**:076001,2001. e-Print: hep-ph/0104120
- Assume all the effect due to B_s^0

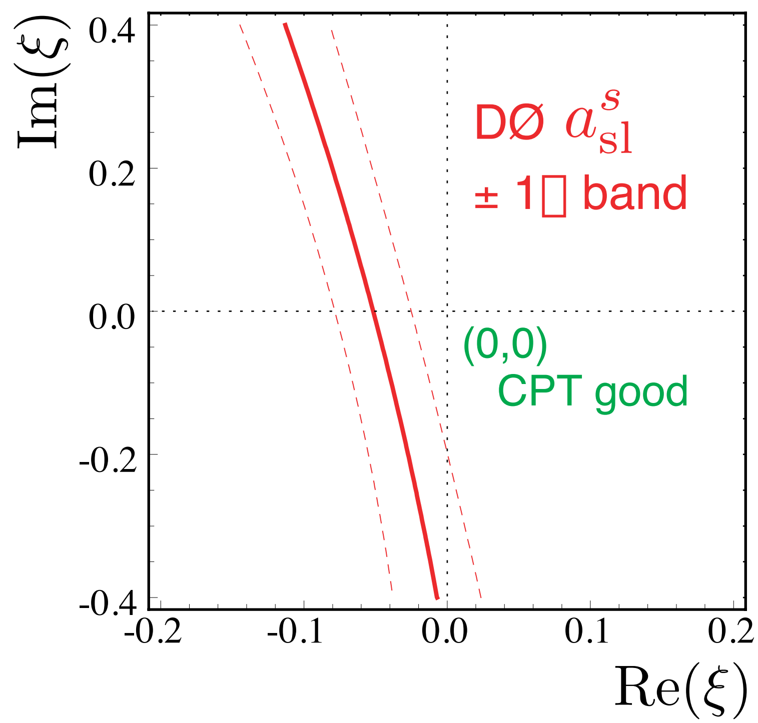
New term in oscillation probabilities (depends on SME coefficients):

$$\xi(\hat{t},\vec{p}) = \frac{\gamma}{\Delta\lambda}[\Delta a_0 + \beta\Delta a_Z \cos\chi + \beta\sin\chi(\Delta a_Y \sin\Omega\hat{t} + \Delta a_X \cos\Omega\hat{t})]$$

Even though not binned in sidereal time, an effect still present!

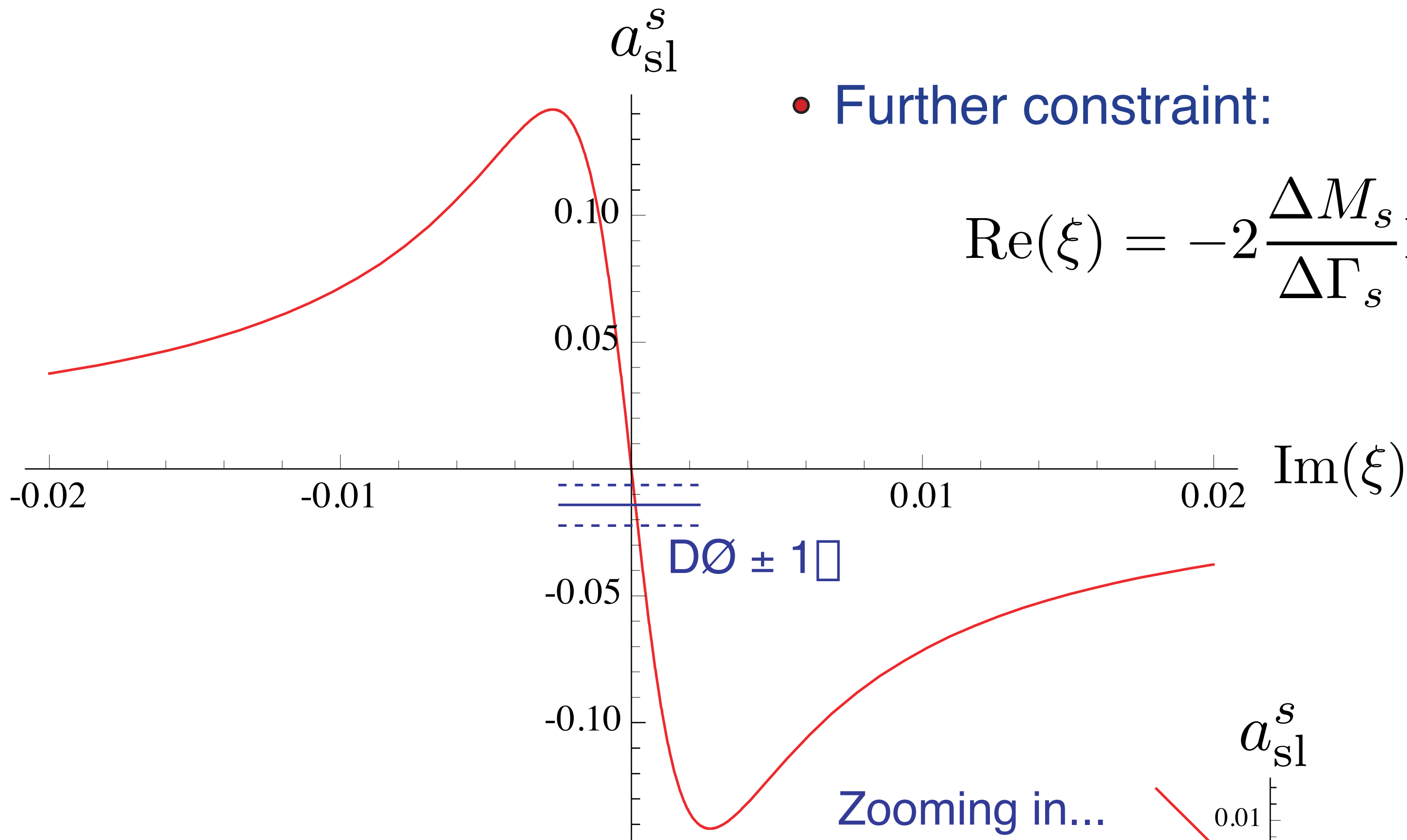
$$|\overline{\xi}| = \overline{\gamma}|\Delta a_0 + \overline{\beta}\Delta a_Z \cos\chi|/|\Delta\lambda|$$

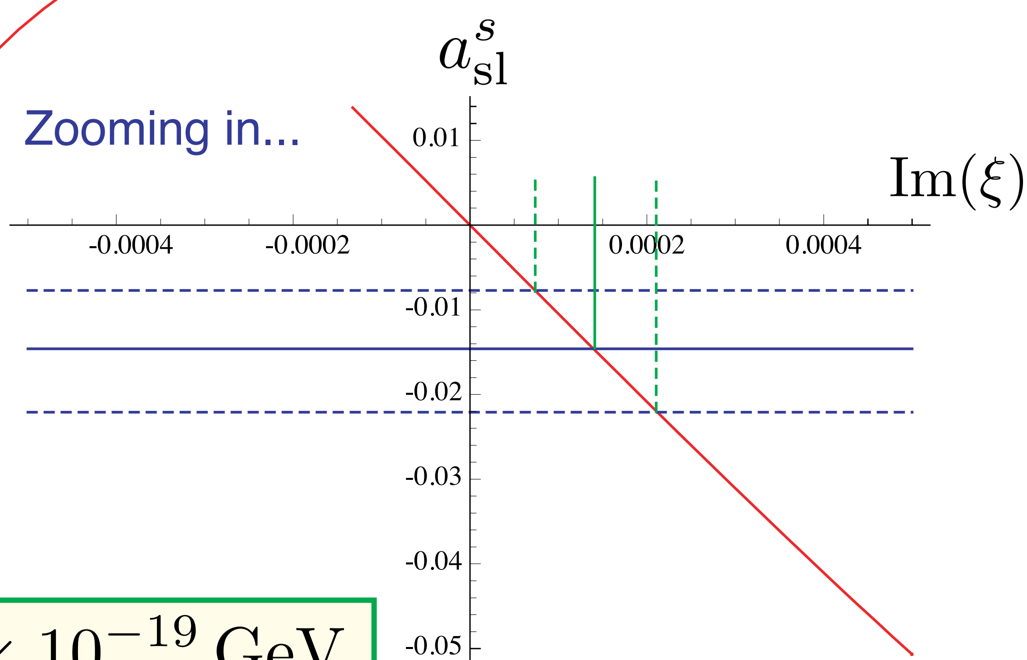
Most general:



- Further constraint:

$$\mathrm{Re}(\xi) = -2\frac{\Delta M_s}{\Delta\Gamma_s}\mathrm{Im}(\xi)$$





**N.B. subsequent CPT treatment & result documented in arXiv:1007.5312 [hep-ph]

$$\boxed{\mathrm{Im}(\xi) = (1.31 \pm 0.67) \times 10^{-4}}$$

$$\boxed{\Delta a_0 + 0.70 a_Z = (9.5 \pm 4.8) \times 10^{-19}\ \mathrm{GeV}}$$

Summary

Specifically

- We have made a new measurement of the like-sign dimuon asymmetry which is significantly different from zero
- Under the assumption it is due to *B*-physics, we extract:

$$\boxed{A_{\mathrm{sl}}^{b} = (-0.957 \pm 0.251\,(\mathrm{stat}) \pm 0.146\,(\mathrm{syst}))\%}$$

- Result is consistent with all other measurements of CP violation in *B* mixing, but inconsistent with the SM at 99.8% CL (3.2σ)
- Obtained using very little input from simulation, and all tests show excellent consistency
- Dominant uncertainty is statistical – precision can be improved with more events (luminosity, triggers, efficiency)
- Both DØ and CDF seeing trends (~95% CL, ~2σ) in independent different analyses sensitive to a similar effect

Summary

General

- Evidence of an anomalous charge asymmetry in the number of muons produced in the initially CP symmetric $p\bar{p}$ interaction
- This asymmetry is not consistent with the SM prediction at a 3.2σ level, but is consistent with other measurements
- Observe that number of produced particles of matter (negative muons) is larger than the number of produced particles of antimatter

  → sign of observed asymmetry is consistent with the sign of CP violation required to explain the abundance of matter in our Universe

This result may be pointing the way to explaining the matter dominance in our Universe

The Last Word

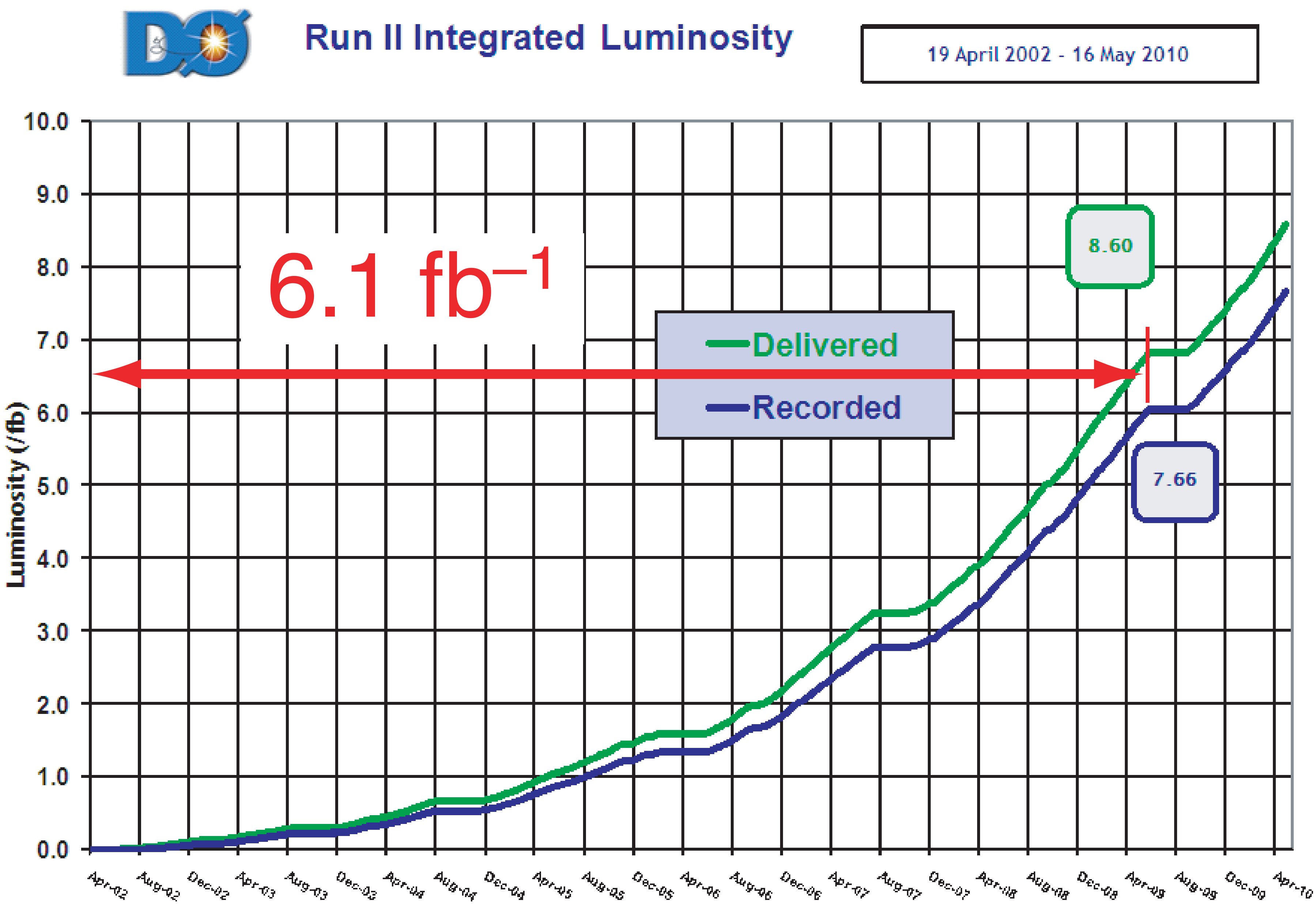
Bill Clinton, Yale's graduation address this Spring:

Again, he reached for a science reference, this time, from particle physics. When protons and antiprotons collide, they should cancel each other out, leaving equal amounts of matter and antimatter. In other words, nothing. But a recent analysis of data from a particle collider suggests that the seemingly nihilistic collisions actually produce slightly more positive than negative elements — eventually allowing life to begin.

“If that’s true,” Clinton said, “it is a metaphor for what you have to do”: create more positive than negative elements.

Backups

Dataset



Run II Integrated Luminosity
19 April 2002 - 16 May 2010
6.1 fb^{-1}
Delivered
Recorded
8.60
7.66
Luminosity (/fb)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Apr-02
Aug-02
Dec-02
Apr-03
Aug-03
Dec-03
Apr-04
Aug-04
Dec-04
Apr-05
Aug-05
Dec-05
Apr-06
Aug-06
Dec-06
Apr-07
Aug-07
Dec-07
Apr-08
Aug-08
Dec-08
Apr-09
Aug-09
Dec-09
Apr-10

Closure Test

Sanity check...

$$a - a_{\mathrm{bkg}} = kA_{\mathrm{sl}}^{b}$$

$$k = 0.041 \pm 0.003$$

inclusive muon asymmetry a dominated by background

$$a \simeq a_{\mathrm{bkg}}$$

- Raw asymmetry:

$$a = (+0.955 \pm 0.003)\%$$

- Background asymmetry estimated from data:

$$a_{\mathrm{bkg}} = (+0.917 \pm 0.045)\%$$

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Do we reproduce the p_T dependence of the background asymmetry?

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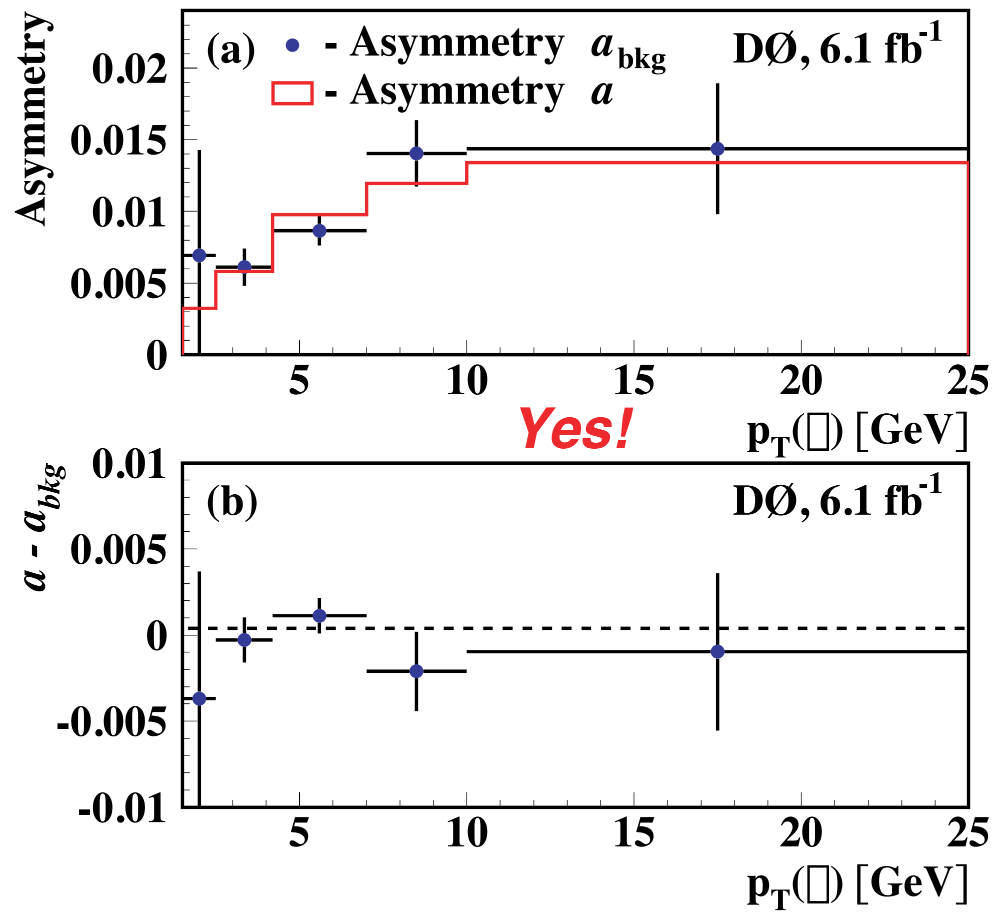


Systematics

	1. Inclusive muon sample	2. Like-sign dimuon sample	1 constraining 2 (Final)
Source	$\delta\sigma(A^b_{\rm sl})(62)$	$\delta\sigma(A^b_{\rm sl})(63)$	$\delta\sigma(A^b_{\rm sl})(65)$
A or a (stat)	0.00066	0.00159	0.00179
f_K or F_K (stat)	0.00222	0.00123	0.00140
$P(\pi \to \mu)/P(K \to \mu)$	0.00234	0.00038	0.00010
$P(p \to \mu)/P(K \to \mu)$	0.00301	0.00044	0.00011
A_K	0.00410	0.00076	0.00061
A_π	0.00699	0.00086	0.00035
A_p	0.00478	0.00054	0.00001
δ or Δ	0.00405	0.00105	0.00077
f_K or F_K (syst)	0.02137	0.00300	0.00128
π, K, p multiplicity	0.00098	0.00025	0.00018
c_b or C_b	0.00080	0.00046	0.00068
Total statistical	0.01118	0.00266	0.00251
Total systematic	0.02140	0.00305	0.00146
Total	0.02415	0.00405	0.00290

Individual Results

- Single muon channel

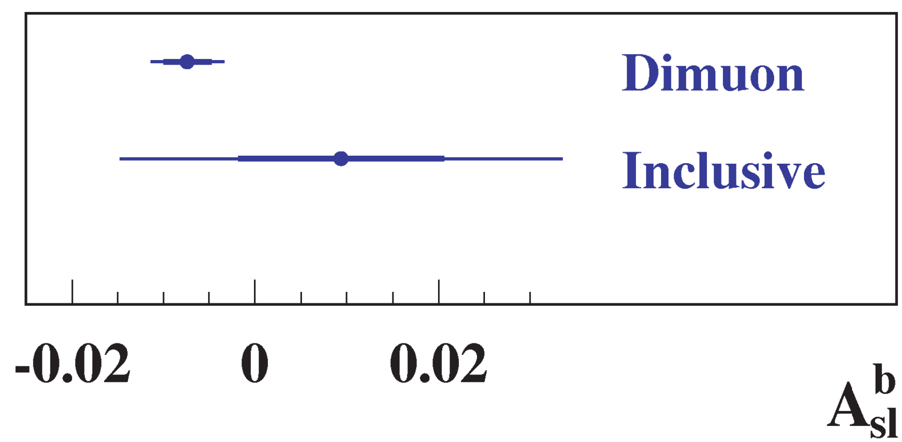
$$A^b_{\mathrm{sl}} = (+0.94 \pm 1.12\,(\mathrm{stat}) \pm 2.14\,(\mathrm{syst}))\%$$

- Like-sign dimuon channel

$$A^b_{\mathrm{sl}} = (-0.736 \pm 0.266\,(\mathrm{stat}) \pm 0.305\,(\mathrm{syst}))\%$$

- Small *k* kills single muon channel sensitivity (as expected)

Good agreement with main result



Reducing Systematic Uncertainty

Two measurements of same quantity:

- One with small signal, large background

$$x_1 = k \cdot A + A_{\mathrm{bkg}}$$

$$A_1 = (x_1 - A_{\mathrm{bkg}})/k$$

- Other large signal, say same background

$$x_2 = K \cdot A + A_{\mathrm{bkg}}$$

$$A_2 = (x_2 - A_{\mathrm{bkg}})/K$$

- Third variable, eliminate background

$$x_3 = (K - k) \cdot A$$

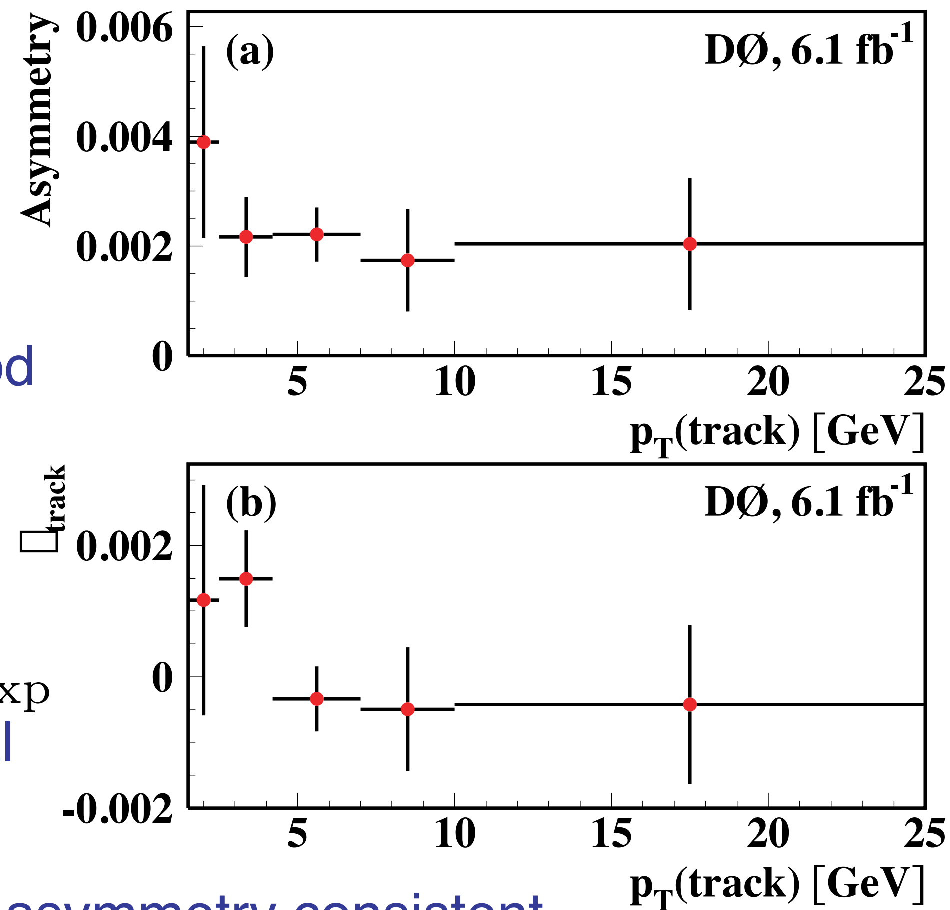
$$A_3 = (x_2 - x_1)/(K - k)$$

Track Reconstruction Asymmetry

- Measure track reconstruction asymmetry using events with one muon and one additional track

- Compute the expected track asymmetry using the same method as in the main analysis, and compare it with the observed asymmetry

- The difference $\delta_{\rm trk} = a_{\rm trk} - a_{\rm exp}$ corresponds to a possible residual track reconstruction asymmetry



- Find residual track reconstruction asymmetry consistent with zero:

$$\boxed{\delta_{\rm trk} = (+0.011 \pm 0.035)\%}$$

- Test A: Part of data sample corresponding to the first 2.8 fb^{-1} (RunIIa) is used.
- Test B: Tight muon selection. In addition to the *reference* selection cuts, we require at least three hits in wire chamber layers B or C, and the χ^2 of the local track fit in the muon detector less than 8.
- Test C: Since the background muons are produced by decays of kaons and pions, their track parameters measured by the central tracker and by the muon system are different. Therefore, the fraction of background strongly depends on the χ^2 of the difference between these two measurements. The cut on this χ^2 is changed from 40 to 4 in this test.
- Test D: The cut on the transverse impact parameter is changed from 0.3 to 0.05 cm, and the cut on the longitudinal distance between the point of closest approach to the beam and the associated vertex is changed from 0.5 to 0.05 cm.
- Test E: Select low-luminosity events by selecting events with less than three primary interactions.
- Test F: Events with the same polarities of solenoid and toroid magnet are used.
- Test G: The cut on the mass of the two muons is changed from 2.8 GeV to 12 GeV.
- Test H: Require that the muon transverse momentum $p_T > 4.2$ GeV.

- Test I: Require that the muon transverse momentum $p_T < 7.0$ GeV.

- Test J: Require that the muon momentum azimuthal angle ϕ be in the ranges $0 < \phi < 4$ or $5.7 < \phi < 2\pi$. This selection excludes muons directed to the region of lower muon identification efficiency.

- Test K: Require that the muon pseudorapidity η be in the range $|\eta| < 1.6$.

- Test L: Require that the muon pseudorapidity η be in the range $|\eta| < 1.2$ or $1.6 < |\eta| < 2.2$.

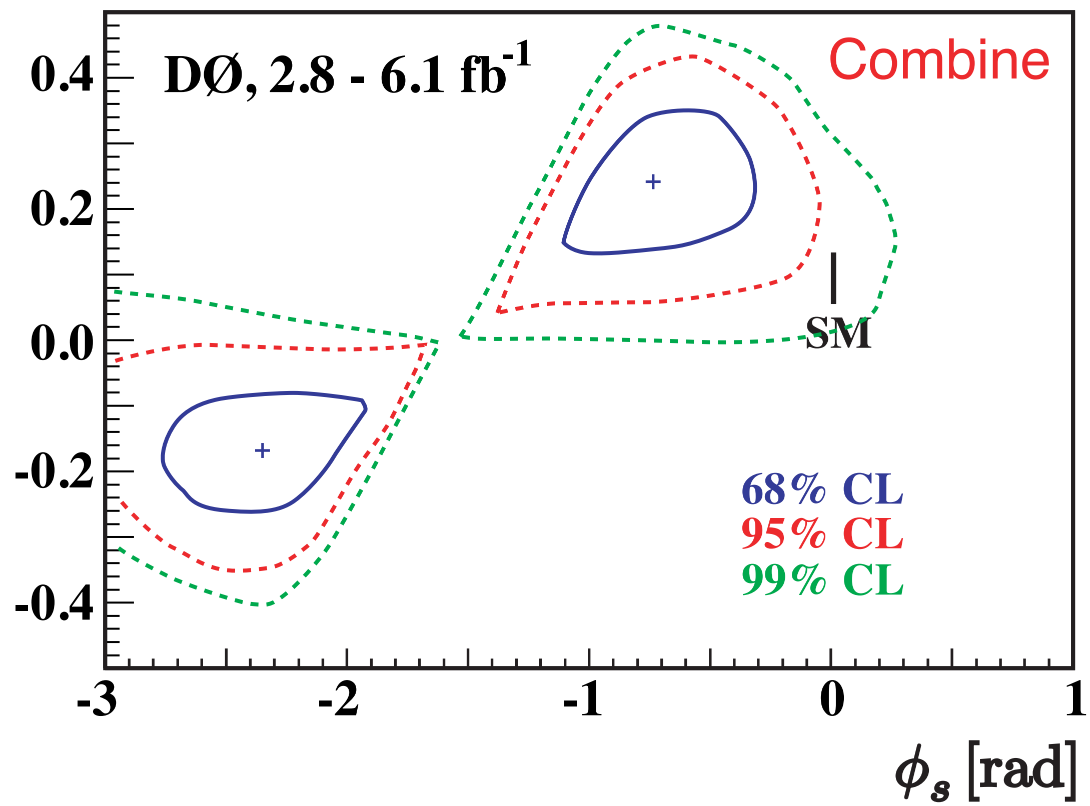
- Test M: Require that the muon pseudorapidity η be in the range $|\eta| < 0.7$ or $1.2 < |\eta| < 2.2$.

- Test N: Require that the muon pseudorapidity η be in the range $0.7 < |\eta| < 2.2$.

- Test O: Like-sign dimuon events passing at least one single muon trigger are used, while the request of a dimuon trigger for these events is dropped.

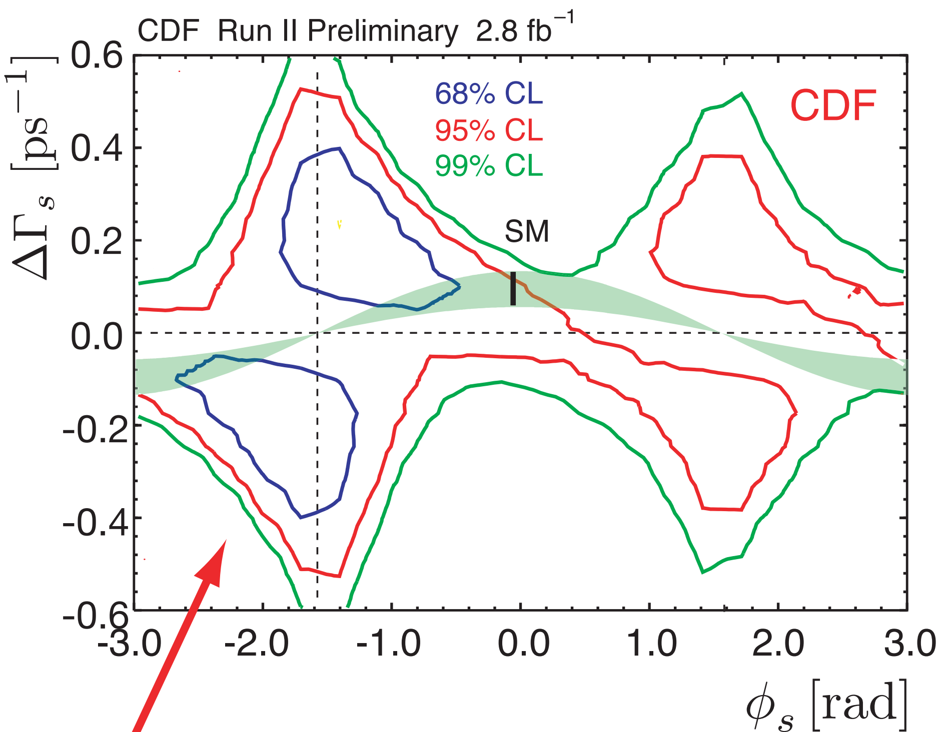
- Test P: Like-sign dimuon events passing both single muon and dimuon triggers are used.

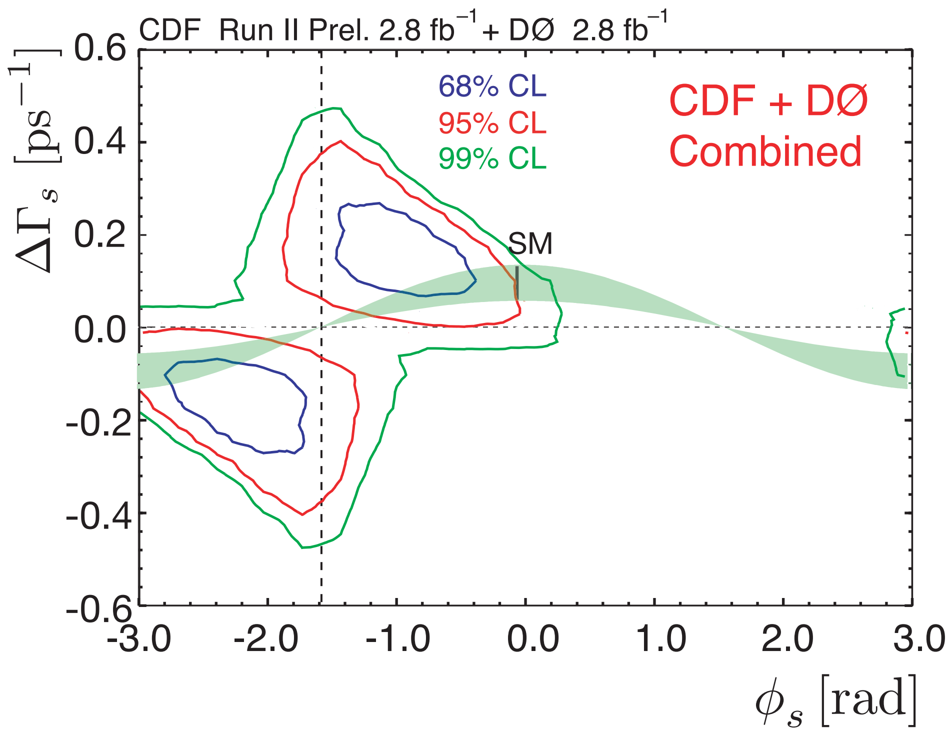
Comparisons using a_{sl}^{s}



Comparisons using a_{sl}^{s}

Tevatron ϕ_s Combination Working Group
DØ Note 5928-CONF (2009),
CDF Public Note 9787 (2009)

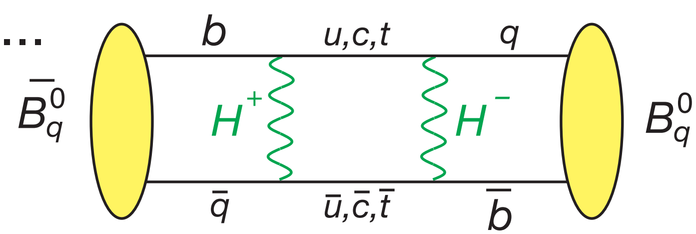




- CDF also observes similar trend in their $B_s^0 \to J/\psi\phi$ analysis, consistent with DØ's; combination shows ~2σ deviation from SM
- CDF update at FPCP2010 with 5.2 fb^{-1}, smaller (0.8σ) deviation from SM (see backup slides)
- DØ working on update with 6.1 fb^{-1}

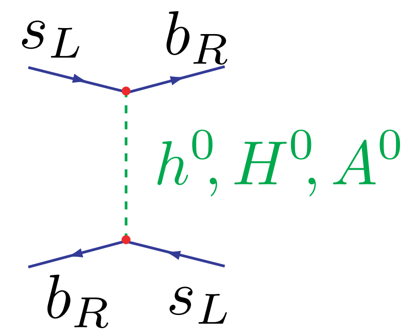
What could it be?

Just give them a bit of time...



In mixing loop...

...or tree level



1. arXiv:1006.0432, *Implications of the dimuon CP asymmetry in B_{d,s} decays*
Zoltan Ligeti, Michele Papucci, Gilad Perez, Jure Zupan

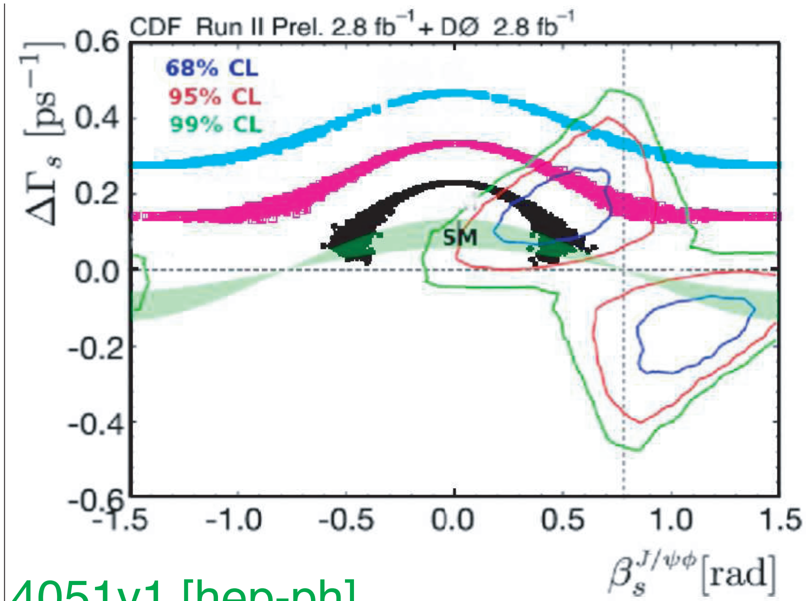
2. arXiv:1005.5310, *Higgs-mediated FCNCs: Natural Flavour Conservation vs. Minimal Flavour Violation*, Andrzej J. Buras, Maria Valentina Carlucci, Stefania Gori, Gino Isidori

3. arXiv:1005.4582, *Axigluon on like-sign charge asymmetry ${\cal A}^b_{s\ell}$, FCNCs and CP asymmetries in B decays*, Chuan-Hung Chen, Gaber Faisel

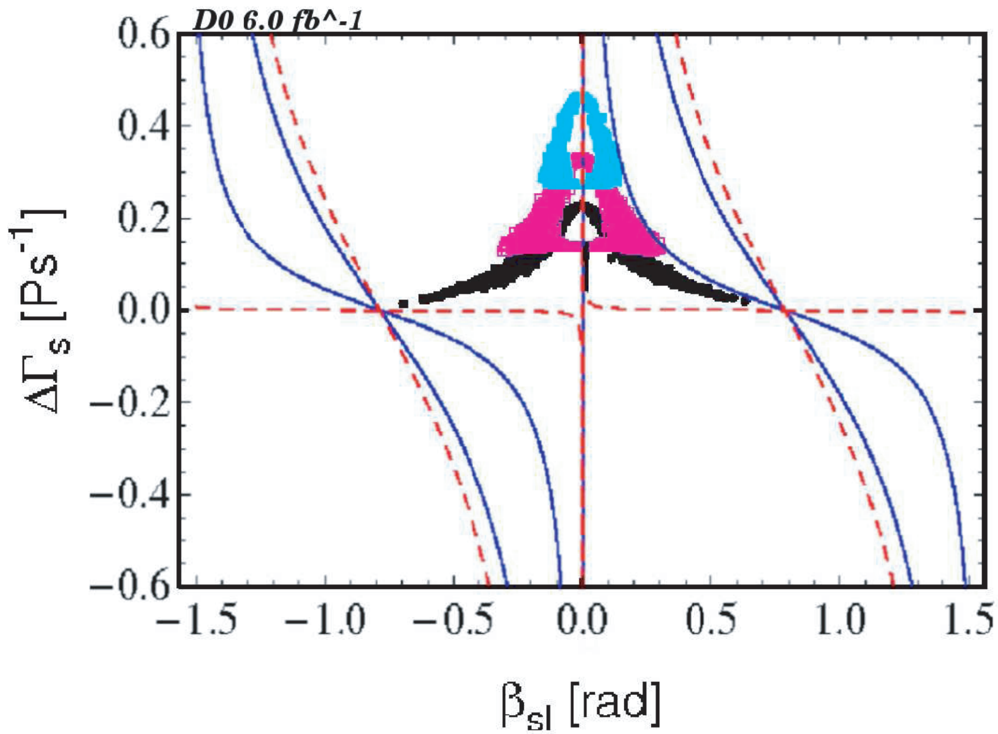
4. arXiv:1005.4238, *CP violation in B_s mixing from heavy Higgs exchange*
Bogdan A. Dobrescu, Patrick J. Fox, Adam Martin

5. arXiv:1005.4051, *Enhanced B_s--$\bar{B}_s$ lifetime difference and anomalous like-sign dimuon charge asymmetry from new physics in $B_s \to \tau^+ \tau^-$*
Amol Dighe, Anirban Kundu, Soumitra Nandi

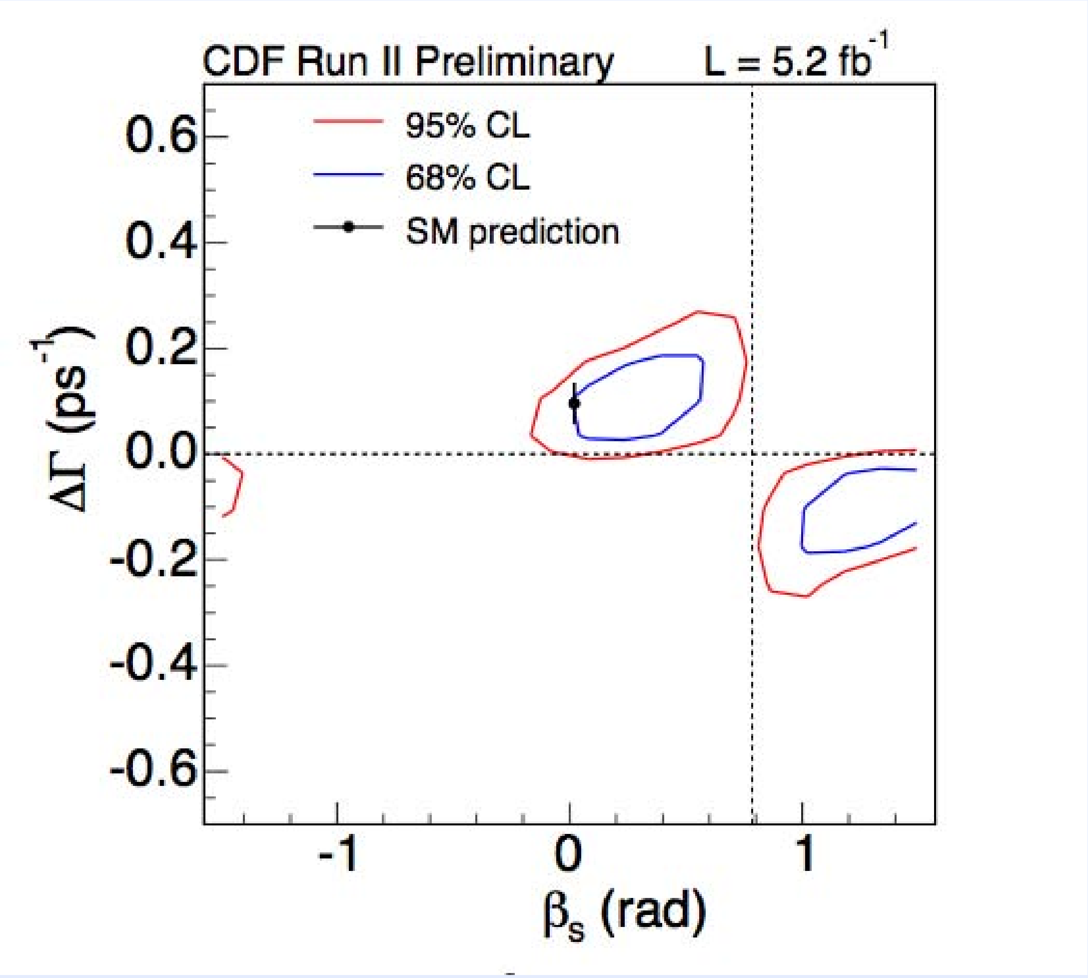
6. arXiv:1005.3505, *Less space for a new family of fermions*
Otto Eberhardt, Alexander Lenz, Jürgen Rohrwild



Dighe et al.,arXiv:1005.4051v1 [hep-ph]



New CDF measurement of β_s



Coverage adjusted 2D likelihood contours for β_s and $\Delta\Gamma$

P-value for SM point: 44%
(0.8σ deviation)

Comparison of data periods